

**TWENTY-FIFTH ANNUAL REPORT**  
**OF THE**  
**NATIONAL ADVISORY COMMITTEE**  
**FOR AERONAUTICS**

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**1939**

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**INCLUDING TECHNICAL REPORTS**  
**NOS. 645 TO 680**



**UNITED STATES**  
**GOVERNMENT PRINTING OFFICE**  
**WASHINGTON: 1940**



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## LETTER OF TRANSMITTAL

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TO THE CONGRESS OF THE UNITED STATES:

In compliance with the provisions of the act of March 3, 1915, establishing the National Advisory Committee for Aeronautics, I transmit herewith the Twenty-fifth Annual Report of the Committee covering the fiscal year ended June 30, 1939.

FRANKLIN D. ROOSEVELT.

THE WHITE HOUSE,  
*January 8, 1940.*



## LETTER OF SUBMITTAL

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NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS,  
*Washington, D. C., December 21, 1939.*

Mr. PRESIDENT:

In compliance with the provisions of the Act of Congress approved March 3, 1915 (U. S. C., title 50, sec. 153), I have the honor to submit herewith the Twenty-fifth Annual Report of the National Advisory Committee for Aeronautics covering the fiscal year 1939.

The Committee is proceeding with the design and construction at Moffett Field, California, of a second major aeronautical research station authorized by Act approved August 9, 1939. This will materially augment and strengthen the Committee's facilities for research in aerodynamics.

Attention is invited to the report of the Special Survey Committee on Aeronautical Research Facilities which appears on page two. In furtherance of its recommendations, a Special Committee on Engine Research Facilities is now studying costs and preparing detailed plans for an additional engine research laboratory.

Respectfully submitted.

VANNEVAR BUSH, *Chairman.*

THE PRESIDENT,  
*The White House, Washington, D. C.*





# NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

HEADQUARTERS, NAVY BUILDING, WASHINGTON, D. C.

LABORATORIES, LANGLEY FIELD, VA.

Created by act of Congress approved March 3, 1915, for the supervision and direction of the scientific study of the problems of flight (U. S. Code, Title 50, Sec. 151). Its membership was increased to 15 by act approved March 2, 1929. The members are appointed by the President, and serve as such without compensation.

VANNEVAR BUSH, Sc. D., *Chairman*,  
Washington, D. C.

GEORGE J. MEAD, Sc. D., *Vice Chairman*,  
West Hartford, Conn.

CHARLES G. ABBOT, Sc. D.,  
Secretary, Smithsonian Institution.

HENRY H. ARNOLD, Major General, United States Army,  
Chief of Air Corps, War Department.

GEORGE H. BRETT, Brigadier General, United States Army,  
Chief Matériel Division, Air Corps, Wright Field, Dayton,  
Ohio.

LYMAN J. BRIGGS, Ph. D.,  
Director, National Bureau of Standards.

ROBERT E. DOHERTY, M. S.,  
Pittsburgh, Pa.

CLINTON M. HESTER, A. B., LL. B.,  
Administrator, Civil Aeronautics Authority.

ROBERT H. HINCKLEY, A. B.,  
Chairman, Civil Aeronautics Authority.

JEROME C. HUNSAKER, Sc. D.,  
Cambridge, Mass.

SYDNEY M. KRAUS, Captain, United States Navy,  
Bureau of Aeronautics, Navy Department.

FRANCIS W. REICHELDERFER, Sc. D.,  
Chief, United States Weather Bureau.

JOHN H. TOWERS, Rear Admiral, United States Navy,  
Chief, Bureau of Aeronautics, Navy Department.

EDWARD WARNER, Sc. D.,  
Washington, D. C.

ORVILLE WRIGHT, Sc. D.,  
Dayton, Ohio.

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GEORGE W. LEWIS, *Director of Aeronautical Research*

S. PAUL JOHNSTON, *Coordinator of Research*

JOHN F. VICTORY, *Secretary*

HENRY J. E. REID, *Engineer in Charge, Langley Memorial Aeronautical Laboratory, Langley Field, Va.*

JOHN J. IDE, *Technical Assistant in Europe, Paris, France*

## TECHNICAL COMMITTEES

AERODYNAMICS  
POWER PLANTS FOR AIRCRAFT  
AIRCRAFT MATERIALS

AIRCRAFT STRUCTURES  
AIRCRAFT ACCIDENTS  
INVENTIONS AND DESIGNS

*Coordination of Research Needs of Military and Civil Aviation*

*Preparation of Research Programs*

*Allocation of Problems*

*Prevention of Duplication*

*Consideration of Inventions*

LANGLEY MEMORIAL AERONAUTICAL LABORATORY  
LANGLEY FIELD, VA.

OFFICE OF AERONAUTICAL INTELLIGENCE  
WASHINGTON, D. C.

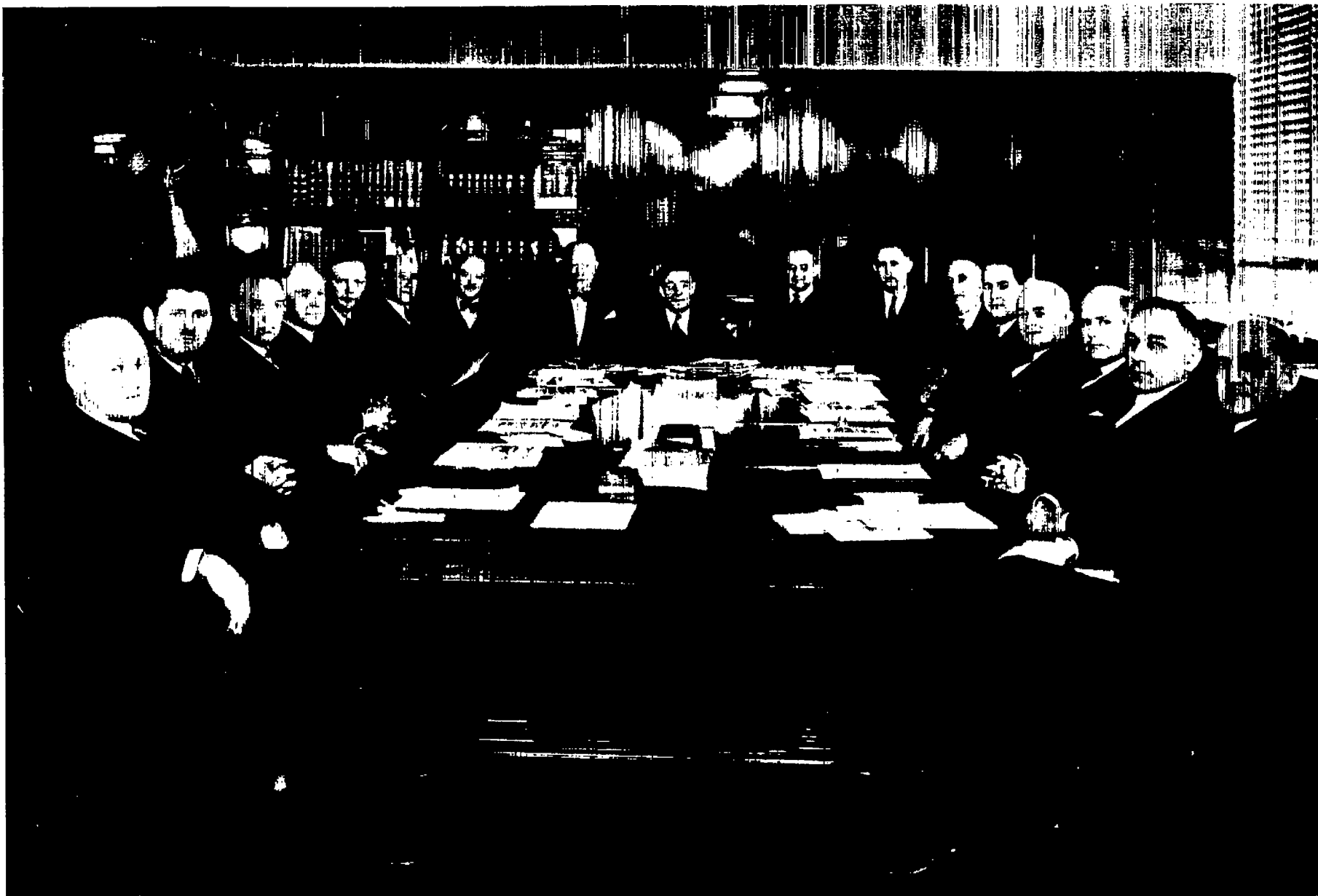
Unified conduct, for all agencies, of scientific research on the  
fundamental problems of flight.

Collection, classification, compilation, and dissemination of  
scientific and technical information on aeronautics.





JOSEPH S. AMES.  
PAST CHAIRMAN, NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS.



NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS.

MEETING, OCTOBER 19, 1939.

Left to right: Brig. Gen. George H. Brett, Army Air Corps; Clinton M. Hester, Administrator, Civil Aeronautics Authority; Rear Adm. John H. Towers, Chief, Bureau of Aeronautics, Navy Department; Dr. L. J. Briggs, Director, Bureau of Standards; Col. Charles A. Lindbergh; Dr. Orville Wright; Dr. J. C. Hunsaker; Dr. George W. Lewis, Director of Aeronautical Research; Dr. Vannevar Bush, Chairman; Dr. George J. Mead, Vice Chairman; John F. Victory, Secretary; Dr. Charles G. Abbot, Secretary, Smithsonian Institution; Dr. Edward P. Warner; Maj. Gen. Henry H. Arnold, Chief, Army Air Corps; Robert H. Hinckley, Chairman, Civil Aeronautics Authority; Capt. S. M. Kraus, U. S. N.; Dr. F. W. Reichebelderfer, Chief, United States Weather Bureau.

# TWENTY-FIFTH ANNUAL REPORT

## OF THE

# NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

WASHINGTON, D. C., *November 16, 1939.*

TO THE CONGRESS OF THE UNITED STATES:

In accordance with the act of Congress approved March 3, 1915 (U. S. C., title 50, sec. 151), which established the National Advisory Committee for Aeronautics, The Committee submits herewith its Twenty-Fifth Annual Report for the fiscal year 1939.

The most significant event of the past year, in its relation to the future of American aeronautics, was the authorization of a second major aeronautical research station for the Committee. This was recommended by the President in February 1939 and was authorized by the Congress in the Third Deficiency Act approved August 9, 1939. The site finally selected by the Committee under authority of that act is Moffett Field, Calif., located about 38 miles south of San Francisco. The details of this important action are set forth in part II of this report. This additional laboratory will serve to relieve the present congestion of work at the Committee's Langley Field laboratory in Virginia and will provide new research facilities necessary to enable the Committee to provide more effectively for an enlarged volume of research work to support and accelerate the technical development of American aircraft.

During the past year important progress was made in many ways in providing, through the Committee's researches at Langley Field, new knowledge which should be the basis of extensive improvements in our aircraft. Discovery during the past year of a new principle in airplane-wing design may prove of great importance. The transition from laminar to turbulent air flow over a wing was so delayed as to reduce the profile drag, or basic air resistance, by approximately two-thirds. It is too early to appraise adequately the significance of this achievement. So far, its application is limited to small airplanes, but there are indications of its ultimate applicability to larger airplanes through continued research. It should increase the range and greatly improve the economy of airplane operation.

This country's opportunity.—The advance of commercial aviation during the past few years has been remarkable. The United States is a country of great expanse, with widely separated centers of population and business activity that will require and support a much larger domestic air transportation system than now exists. Increased economy and reduced dependency upon financial aid from the Government, where such aid still exists, depend on technical progress and improvement in the inherent characteristics of the aircraft used.

The United States was the first to establish regular commercial air transport service over the North Atlantic and the Pacific Oceans. Recent progress in the attainment of a high degree of safety in air transportation is most gratifying in this connection. The long distances between the United States and Alaska, and between the United States and the South American Republics, require faster and more efficient air transportation. The development of commercial transport airplanes of ever-increasing efficiency and safety can be accelerated by investigations in our research laboratories.

Unprecedented expansion of air power.—From the standpoint of national defense, the United States is most fortunately situated between two great oceans. However, as advances in aeronautical science result in increased range of aircraft the significance of these oceans will gradually diminish and superiority in aircraft design will become more and more essential to our national safety. The year 1939, prior to the outbreak of the European War, was notable as witnessing unprecedented expansion of air power in many nations. Germany has concentrated much of its scientific and industrial resources on the problem of gaining supremacy in the air. England and France are making every effort in the same direction. Research facilities have been greatly expanded in all the major nations.

Relation of aeronautical research to national defense.—The effectiveness of an air force is largely dependent on constant activity in research laboratories necessary to

insure continuous improvement in design and performance of aircraft. Orderly prosecution of comprehensive programs of scientific research is indispensable. It is the function of the National Advisory Committee for Aeronautics to "supervise and direct the scientific study of the problems of flight with a view to their practical solution," and to "direct and conduct research and experiment in aeronautics" in such laboratories as may be placed under its direction. The Committee has for many years exercised these functions, by the direct conduct of research in its own laboratories and also by contractual relations with independent laboratories.

To coordinate the research needs of aviation, civil and military, and to prepare programs of research in the various branches of science affecting aeronautics, the Committee has established four major standing technical subcommittees, on aerodynamics, power plants for aircraft, materials for aircraft, and aircraft structures. There are also other special and subordinate subcommittees. The subcommittees are composed in part of specially qualified representatives of the governmental agencies concerned. The main committee, upon recommendations of subcommittees or upon its own initiative, authorizes research programs. The results of researches are either published or kept secret or confidential, as may be advisable in the national interest, but they are always brought promptly to the attention of the proper parties in the Government and in cooperating industry.

**Enlarged plan for coordination.**—The Committee, in order to exercise more fully its functions, has adopted a program of coordination of research as recommended by a special committee appointed to study that subject. The coordination of research entails for the Committee the duty of maintaining close liaison with all organizations, governmental and private, that operate research facilities. This is for the purpose of providing for the utilization, to the maximum advantage of the United States, of available research facilities in the pursuit of a coordinated program.

The Committee is cooperating with the War and Navy Departments, the Civil Aeronautics Authority, and other agencies of the Government to the fullest extent, to the end that the new facilities now being provided by the Committee and by other governmental agencies shall be of the maximum scope that can be provided with the funds available and of proper balance as to character.

**Necessary expansion of research.**—The year 1940 will mark the twenty-fifth anniversary of the Committee's establishment. As the Committee reviews the effects of scientific research on the progress of aeronautics during the last quarter of a century, it is convinced that the systematic conduct of scientific research is the most fundamental activity of the Government in connection with the development of aeronautics. The

Committee is gratified to have had the confidence and support of the President and of the Congress in the past. The years that lie immediately ahead will be critical years in the development of aeronautics. The Committee's work will need to be carried out on an even broader front and on a larger scale in the immediate future.

Because of the increasing relative importance of aeronautics in national defense and in transportation, the Committee believes that the needs of the country justify a further immediate expansion of research activities in two directions, namely, the establishment of an engine research laboratory, and additional stimulation of aeronautical research in educational and scientific institutions.

With Colonel Charles A. Lindbergh as chairman, Major General Henry H. Arnold, Chief of the Army Air Corps, Rear Admiral John H. Towers, Chief of the Bureau of Aeronautics, Navy Department, and Honorable Robert H. Hinckley, Chairman of the Civil Aeronautics Authority, have served as a Special Survey Committee on Aeronautical Research Facilities. That committee, under date of October 19, 1939, submitted a report to the National Advisory Committee for Aeronautics as follows:

#### REPORT OF THE SPECIAL SURVEY COMMITTEE ON AERONAUTICAL RESEARCH FACILITIES

In accordance with the directions to this special committee to "examine into the aeronautical research facilities now available in the country and their best interrelationship, and to prepare a comprehensive plan for the future extension of such facilities, with especial attention to facilities of the N. A. C. A. and the universities," the following report is submitted, supplementing the committee's previous reports.

As a result of its studies, this committee finds that there is a serious lack of engine research facilities in the United States, and that it is of the utmost importance for the development of aviation in general, and for our defense program in particular, to take immediate steps to remedy this deficiency.

This committee, therefore, urgently recommends that an engine research laboratory be constructed at the earliest possible date, in a location easily accessible to the aircraft-engine industry.

In making this recommendation, the committee wishes to call attention to the fact that the reason for foreign leadership in certain important types of military aircraft is due in part to the superiority of foreign liquid-cooled engines. At the present time, American facilities for research on aircraft power plants are inadequate and cannot be compared with the facilities for research in other major fields of aviation.

This committee also recommends that an investigation be made of the engine research facilities which may be available at universities and other scientific organizations, with a view to coordinating these facilities and encouraging their most effective use. The committee is more than ever impressed with the desirability of using to the fullest possible extent the research facilities available in universities and other scientific organizations. The committee believes that the proper use and coordination of these facilities is one of the most

important functions that can be carried on by the National Advisory Committee for Aeronautics.

The foregoing report was unanimously approved at a full meeting of the National Advisory Committee for Aeronautics. To start action on the first recommendation, a Special Committee on Engine Research Facilities was immediately organized under the chairmanship of Dr. George J. Mead, Vice Chairman of the main Committee, and instructed to submit to the main committee a final report with detailed plans.

The Committee had anticipated the second recommendation by including in its regular estimate for the ensuing year an additional amount for research in educational and scientific institutions. This is enlarging the procedure which the Committee has followed since its beginning. In recent years the facilities of educational institutions for conducting research in aeronautics have increased and there is now an opportunity for much greater effectiveness in accelerating progress by substantially enlarging the Committee's employment of these facilities. The Committee cannot too strongly urge the importance of the proposed appropriation, for not only will it yield direct results in the form of new contributions to knowledge along a variety of lines for which the facilities and personnel of such institutions are well adapted, but it will also result in the training of research workers in aeronautics for the benefit alike of the governmental services and of the industry.

Quite as important as liberal appropriations for any aeronautical purpose is the adoption of a farsighted policy to develop trained technical personnel. The Committee believes that the stimulation of aeronautical research in scientific and educational institutions, as proposed, is the most effective and, incidentally, the most economical way to develop in larger numbers and in a democratic manner the talented individuals having the scientific training necessary to engage successfully in what has become an international competition.

**Resignation of Dr. Joseph S. Ames, Chairman.**—On October 7, 1939, Dr. Joseph S. Ames resigned as member and Chairman of the National Advisory Committee for Aeronautics, because his physical condition would not permit him to "take a sufficiently active part in the great work that confronts the Committee."

Dr. Ames was the last of the original members of the Committee appointed by President Wilson in 1915. He had been reappointed in 1938 by President Roosevelt for a 5-year term. For 17 years he was Chairman of the Executive Committee (1919-36), and for 12 years he was Chairman of the main Committee (1927-39). His long service included 8 years as Chairman of the Committee on Aerodynamics (1919-27) and the chairmanship of other important subcommittees, and also of the annual engineering research conferences

with the aircraft industry, and of the special conferences on nomenclature for aeronautics held in 1920, 1922, 1925, and 1933. In 1923, he delivered the Wilbur Wright Memorial lecture before the Royal Aeronautical Society of Great Britain on the subject, "The Relation Between Aeronautical Research and Aircraft Design."

In 1935 Dr. Ames was awarded the Langley Gold Medal by the Board of Regents of the Smithsonian Institution "in recognition of the surpassing improvement of the performance, efficiency, and safety of American aircraft resulting from fundamental scientific researches conducted by the National Advisory Committee for Aeronautics under the leadership of Dr. Ames."

Dr. Ames, while serving as professor of physics and later as president of the Johns Hopkins University at Baltimore, Md., had devoted himself unsparingly to the work of the Committee without compensation or thought of reward. The President of the United States, in accepting his resignation on October 10, 1939, wrote as follows:

THE WHITE HOUSE,  
Washington, October 10, 1939.

Dr. JOSEPH S. AMES,  
Guttford, Baltimore, Md.

MY DEAR DR. AMES: It is with sincere regret that I accept your resignation as a member of the National Advisory Committee for Aeronautics, submitted because of your physical inability to take an active part in the Committee's work at this critical time.

Our Republic would not be worthy of the devoted service you have rendered for over 24 years without compensation if it could not on this occasion pause to pay tribute where it is so justly due.

When you were first appointed by President Wilson in 1915, very little was known about the science of aeronautics. To you and to your colleagues were entrusted by law the supervision and direction of the scientific study of the problems of flight. For the past 20 years you have served as Chairman of the National Advisory Committee for Aeronautics, or Chairman of its Executive Committee. The administration and the accomplishments of the Committee under your leadership reflect your great scientific attainments, professional courage, and executive ability.

That the people generally have not known of your brilliant and patriotic service is because it has been overshadowed by your passion for accomplishment without publicity. But the fact remains, and I am happy to give you credit for it, that the remarkable progress for many years in the improvement of the performance, efficiency, and safety of American aircraft, both military and commercial, has been due largely to your own inspiring leadership in the development of new research facilities and in the orderly prosecution of comprehensive research programs.

I wish you many years of peace and contentment in which to enjoy the satisfaction that should be yours as you view the continuing results of your labors.

Very sincerely yours,

FRANKLIN D. ROOSEVELT.

The limitations of a public document preclude the presentation of a full account of Dr. Ames' contribu-

tions to the advancement of the science of aeronautics. In view of his outstanding record of public service, it is deemed appropriate to publish the fact that at a full meeting of the National Advisory Committee for Aeronautics held in Washington, D. C., on October 19, 1939, at which the resignation of Dr. Ames was announced, by unanimous rising vote of the members, the following testimonial to Dr. Ames was adopted:

*Resolved*, That the members of the National Advisory Committee for Aeronautics do adopt and approve the following tribute to their distinguished past Chairman:

For over 20 years Dr. Ames has served as Chairman of the National Advisory Committee for Aeronautics or as chairman of its executive committee. His long service leaves upon the organization the indelible imprint of his character. He is not only a great scientist, he is a great man, and we are proud to have been associated with him.

When aeronautical science was struggling to discover its fundamentals, his was the vision that saw the need for novel research facilities and for organized and sustained prosecution of scientific laboratory research. His was the professional courage that led the Committee along new scientific paths to important discoveries and contributions to progress that have placed the United States in the forefront of progressive nations in the development of aeronautics. His was the executive ability and farsighted policy of public service that, without seeking credit for himself or for the Committee, developed a research organization that holds the confidence of the governmental and industrial agencies concerned and commands the respect of the aeronautical world. Withal, Dr. Ames was an inspiring leader of men and a man beloved by all his colleagues because of his rare personal qualities.

Dr. Ames' retirement from active duty because of his physical inability to carry on is sincerely regretted by all who know of his unparalleled service to American aeronautics.

*Resolved further*, That the Chairman be authorized to appoint a special committee to present this testimonial to Dr. Ames with our heartfelt thanks for all that he has done for the Committee and with our sincere wishes that he may be spared for many years to witness in peace and contentment the continuing fruits of his labors.

The foregoing testimonial to Dr. Ames was engrossed and signed by all the members of the Committee. It

was presented to Dr. Ames at his residence in Baltimore on October 23 by a special committee composed of Dr. Edward Warner, Chairman; Dr. Vannevar Bush, Dr. Lyman J. Briggs, Dr. George W. Lewis, and Mr. John F. Victory. Dr. Warner made the presentation with appropriate expression of the great admiration and esteem in which Dr. Ames is held by all members of the Committee.

*Recommendations.*—The Committee urgently recommends that it be authorized to construct an engine research laboratory at the earliest possible date in a location easily accessible to the aircraft-engine industry. The Special Survey Committee on Aeronautical Research Facilities, as a result of its studies, found "that there is a serious lack of engine research facilities and that it is of the utmost importance for the development of aviation in general, and for our defense program in particular, to take immediate steps to remedy this deficiency." That special committee called attention to the fact that the reason for foreign leadership in certain important types of military aircraft is due in part to the superiority of foreign liquid-cooled engines, and added that "at the present time American facilities for research on aircraft power plants are inadequate and cannot be compared with the facilities for research in other major fields of aviation." Detail studies are being made by the Special Committee on Engine Research Facilities, which will probably develop plans for the construction of an engine research laboratory on a site to be selected by the Committee.

The Committee's regular estimates of appropriations for the fiscal year 1941 include an increased appropriation for the stimulation of aeronautical research in scientific and educational institutions by contracting for research in these institutions supplementing research in Government laboratories. It is strongly recommended that this be approved.



## PART I

### REPORTS OF TECHNICAL COMMITTEES

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In order to carry out effectively its principal function of the supervision, conduct, and coordination of the scientific study of the problems of aeronautics, the National Advisory Committee for Aeronautics has established a group of technical committees and subcommittees. These technical committees prepare and recommend to the main Committee programs of research to be conducted in their respective fields, and as a result of the nature of their organization, which includes representation of the various governmental agencies concerned with aeronautics, they act as coordinating agencies, providing effectively for the interchange of information and ideas and the prevention of duplication.

In addition to its standing committees and subcommittees, it is the policy of the National Advisory Committee for Aeronautics to establish from time to time special technical subcommittees for the study of particular problems as they arise.

The Committee has four principal technical committees—the Committee on Aerodynamics, the Committee on Power Plants for Aircraft, the Committee on Aircraft Materials, and the Committee on Aircraft Structures. Under these committees there are six standing subcommittees. The membership of these technical committees and subcommittees is listed in part II.

The Committees on Aerodynamics and Power Plants for Aircraft prepare the programs for, and keep in touch with, the aerodynamic and aircraft-engine research, respectively, conducted at the Committee's laboratory at Langley Field, and of special investigations conducted at the National Bureau of Standards. Most of the research under the cognizance of the Committee on Aircraft Materials is conducted by the National Bureau of Standards. A large part of the research under the cognizance of the Committee on Aircraft Structures is carried on by the National Bureau of Standards. In addition, a number of structural investigations, including in particular investigations of a theoretical nature, are conducted at the Committee's laboratory at Langley Field and at educational institutions.

The four technical committees recommend to the main Committee the investigations in their respective fields to be undertaken by educational institutions un-

der contract with the National Advisory Committee for Aeronautics, and keep in touch with the progress of the work and the results obtained. The experimental investigations in aerodynamics, aircraft power plants, aircraft materials, and aircraft structures undertaken by the Army Air Corps, the Bureau of Aeronautics of the Navy, the National Bureau of Standards, and other Government agencies are reported to these four committees.

#### REPORT OF COMMITTEE ON AERODYNAMICS

##### LANGLEY MEMORIAL AERONAUTICAL LABORATORY

##### LANDING SPEED AND SPEED RANGE

The emphasis now being placed on the high-speed performance of military airplanes is resulting in marked increases in wing loadings and is creating a strong demand for improved high-lift devices. To meet this demand, the Committee has been devoting increasing effort to the investigation of the more promising types of partial- and full-span flaps.

The investigation of wings with slotted flaps in the 7- by 10-foot wind tunnel has been extended to include airfoils having thickness ratios of 21 and 30 percent. For the airfoil of 21-percent thickness (Technical Report No. 677), the maximum lift coefficient obtained with the best slotted flap was about the same as for the airfoil of 12-percent thickness (Technical Report No. 664). With the 30-percent-thick airfoil, however, the maximum lift coefficient obtained was about 10 percent less with the best slotted flap than for the thinner airfoils. The drag for a given lift coefficient increased with airfoil thickness; therefore, the best speed-range ratio was obtained with the thinnest airfoil. The investigation has also been extended to cover wide-chord slotted flaps on airfoils of the three thicknesses. Results of tests of the N. A. C. A. 23012 and 23021 airfoils with 40-percent-chord flap (Technical Notes Nos. 715 and 728) showed no appreciable gain in maximum lift coefficient over the 25-percent-chord flap. The thicker airfoil had a considerably higher drag coefficient.

The results of an investigation in the 7- by 10-foot wind tunnel of a multiple-flap arrangement mentioned

in the last annual report have been published as Technical Report No. 679. The investigation of double-slotted flaps has been extended to flaps of wider chord and to airfoils of different thicknesses.

Tests have been made in the 7- by 10-foot wind tunnel on a rectangular and a tapered N. A. C. A. 23012 wing with partial-span slotted flaps. The results of these tests, published in Technical Note No. 719, are similar to the results on the partial-span plain and split flaps previously reported; greater increments of maximum lift were obtained with the slotted flaps.

An investigation has been made (Technical Note No. 699) in the 7- by 10-foot wind tunnel on a slotted deflector-plate flap on an N. A. C. A. 23012 airfoil. This flap gave on this airfoil a somewhat lower maximum lift coefficient than the best slotted flap of the same chord.

Tests have also been made in the 7- by 10-foot wind tunnel of split flaps of 10-, 20-, 30-, and 40-percent chord on N. A. C. A. 23012, 23021, and 23030 airfoils. The results of these tests have been published in Technical Report No. 668. It was found that the final maximum lift coefficients for the three airfoils with 20-percent-chord flaps were equal; for airfoils with 10-percent-chord flaps the maximum lift coefficient decreased with airfoil thickness; and for the flaps of 30- and 40-percent chord, the maximum lift coefficient increased with airfoil thickness.

Data dealing with the air loads on flaps and slats have been collected from various sources, correlated, and published as Technical Note No. 690.

#### CONTROL AND CONTROLLABILITY

**Variation of control effectiveness with airplane size.**—During the past year investigations of the flying qualities of a number of airplanes, ranging in weight from 4,500 to 70,000 pounds, have provided considerable data on the variation of control effectiveness with airplane size. With regard to the aileron control, the reduction in effectiveness with increased wing span, as indicated by the maximum rolling velocity, was found to be greatly in excess of that indicated by the theoretical relationship because of the large aileron hinge moments and the excessive stretch of the control cable. These characteristics prevented the pilot from using what would normally be full aileron and in one instance imposed a severe limit on the aileron control at high speeds. The need for improvement in design to permit full deflection of the ailerons was indicated.

Many of the airplanes investigated displayed strong tendencies to turn in the direction of a low wing following a disturbance from laterally level flight, with resulting difficulty in maintaining a straight course in rough air. In certain instances yawing occurred against full rudder with the wing down less than 5°.

As a result of this characteristic, increased demands were made on the ailerons to maintain the wings level.

The effectiveness of the elevator and the rudder controls was adequate in all the machines tested.

**Lateral controls for use with full-span flaps.**—Because of the inadequacy of partial-span flaps on airplanes with the high wing loadings now contemplated, the development of an acceptable lateral-control device for use on wings employing high-lift devices over the entire span will be necessary.

An investigation has been made in flight (Technical Note No. 714) of retractable ailerons on a wing of 5:1 taper equipped with full-span plain flaps. Although the lateral control obtained with this particular installation was considered inadequate, the deficiency can apparently be ascribed to the fact that the aileron span amounted to only 33 percent of the wing span. With conventional ailerons of approximately the same span, mounted on the same wing, the airplane was equally deficient in lateral control. The lack of an appreciable stick force required to operate the retractable ailerons was considered too small to be desirable for a small airplane, although these ailerons appeared to be satisfactory in other respects.

The investigation in the 7- by 10-foot wind tunnel of lateral-control devices to be used in conjunction with full-span flaps has been continued. The equipment has been modified to make possible a more accurate determination of the time-response characteristics of the various devices than was heretofore possible. Comparative tests have been made on a large variety of devices on plain wings and on wings with full-span split and slotted flaps. The static rolling and yawing moments were determined for all the devices, and the time-response and the hinge moments were determined for most of the devices.

In recent investigations two lateral control systems have been developed for use with full-span flaps, both of which appear to offer promise for successful application.

#### STABILITY

The investigation of flying qualities has contributed much information on the stability of existing airplanes. Several points of general weakness have been noted and are being carefully studied. All the airplanes tested have displayed a tendency to spiral with the controls free. The situation is not considered serious, but complete stability is believed to be a desirable if not an essential characteristic when the requirements do not conflict with those of other essentials. In this connection, it has been noted that irreversible controls or a great amount of control friction are not remedies. When such measures were used, the lack of self-centering action of the controls masked the inherent

stability characteristics of the airplane and always produced a condition of apparent instability.

Many of the airplanes would be improved by increased directional stability. In one case a large diving moment was found to occur when the airplane was yawed. This characteristic, together with nearly neutral directional stability, resulted in frequent changes in longitudinal trim and a general feeling of uncertainty on the part of the pilot. Increased vertical fin area increased the steadiness of this airplane.

Observations of the angles of bank and the accompanying angles of yaw during steady sideslips have indicated a general inability of modern airplanes to develop cross-wind force. As a result of this characteristic, the pilot can judge the severity of a sideslip only by the rudder force and, where the directional stability of the airplane is small, large angles of yaw may be unknowingly attained. In some cases it was found relatively easy to obtain such large angles of yaw that the vertical tail stalled and directional instability was produced. This condition is to be avoided, particularly in large airplanes, in view of the large rudder forces required to regain control.

As a class, the low-wing monoplanes tested have been undesirably weak in longitudinal stability. The midwing and the high-wing monoplanes have exhibited somewhat more satisfactory characteristics, particularly at low speeds, where an increasing degree of stability is desired as a stall warning. None of the airplanes, however, has been completely satisfactory in this respect.

Several studies dealing with the stability of the complete airplane are still in progress. An analysis of the relationship between the longitudinal-control characteristics and the elevator-control effectiveness is practically complete, and a report on the subject will be shortly prepared. The analysis indicates that although the elevator force required for steady flight varied directly with the degree of stability, the force required to produce speed changes decreased only 50 percent when the center of gravity was moved rearward 15 percent of the wing chord to the position that gave zero stability. The investigation of lateral stability with the automatic pilot is also nearing completion. Charts have been drawn to show the correlation of rudder and aileron mechanisms for stability. These data are being prepared for publication.

The function of the rudder and the manner in which this control is influenced by the degree of lateral stability are being investigated. Several tentative criteria have been formulated that when completed may be used directly in design.

A model has been built and tests have started with the gust-tunnel apparatus to determine the effect of

longitudinal stability on the structural loads due to gusts.

Research has been continued on the influence of the design variables on the stability derivatives. The effect of yaw on the lateral-stability characteristics of four N. A. C. A. 23012 wings tested in the 7- by 10-foot wind tunnel is described in Technical Note No. 703. The wing variables investigated were taper, sweep, dihedral, and flap deflection. Technical Note No. 730 describes the effect on the stability characteristics of the position of a rectangular N. A. C. A. 23012 wing when combined with a circular fuselage. The wing was tested in three positions—high, mid, and low. The difference between the high and the low positions was approximately equivalent to 5° dihedral.

Tests have also been made in the 7- by 10-foot wind tunnel to obtain an indication of the difference between single and twin vertical tail surfaces as regards their contribution to the static directional and control forces.

In order to aid in the design of horizontal tail planes for longitudinal stability, a large number of stream-angle and dynamic-pressure surveys have been made in the wake of airfoils and wings of airplane models and airplanes. These data have been correlated with theory. The downwash angles computed from the theoretical span load distribution were found to be in satisfactory agreement with the experimental results. It was also found that by theoretical treatment the wake characteristics can be predicted in terms of distance behind the trailing edge of the wing and the profile-drag coefficient of the wing. The results of this work are presented in Technical Report No. 651.

Technical Report No. 648 presents graphs from which the airplane designer may readily determine the downwash angle in the tail-plane region for elliptical and tapered wings within a practicable range of aspect ratios and with various flap arrangements. Charts and formulas are also included for evaluating the wake width and the velocity distribution in the wake.

The designer has been provided with information on the aerodynamic characteristics of tail planes by an extensive series of tests made on an isolated tail plane in the full-scale tunnel. The effects of various types of elevator nose shape, amount of elevator balance, and gap between the elevator and the stabilizer were investigated. In addition to the usual force-test results, determinations were made of the elevator hinge moment for all conditions, including the use of various sizes of tab. Technical Report No. 675 presents these data.

Further information on the aerodynamic characteristics of the tail surfaces is being furnished by the measurement of section characteristics in the 4- by 6-foot wind tunnel. The test program calls for the systematic variation of elevator or rudder chord and a detailed study of different means of balancing the hinge mo-

ments. The first phase of the work, consisting of pressure distribution tests of an N. A. C. A. 0009 airfoil with three sizes of unbalanced movable surfaces each with three sizes of tabs, is well advanced. One paper on the subject has been prepared for publication.

During the past year, the laboratory facilities for the study of stability have been augmented by the completion of a new 12-foot free-flight wind tunnel. The construction of this tunnel completes the development of the free-flight type of tunnel that has been in progress for several years. In this type of wind tunnel, a model is flown by remote control free from any restraint. Continuous observations may be made by a stationary observer of the inherent and the controlled stability, the motion in gusty air, the stalling characteristics, and many other factors directly related to the free-flight behavior of the airplane. Preliminary investigations on the stability of two service airplanes conducted in the model of the tunnel used for development work have indicated that the 12-foot free-flight tunnel offers a useful, rapid, and relatively inexpensive means for the study and the correction of the stability and the handling characteristics of new airplane designs. The 12-foot tunnel is being calibrated, and testing will shortly be started.

#### SPINNING

The determination, and improvement where needed, of the spinning characteristics of new service airplane designs in the 15-foot free-spinning wind tunnel have been continued. During the past year the characteristics of five specific designs were inspected. As usual, the findings in these investigations were immediately transmitted to the service organizations concerned. The Committee, however, has also compiled and analyzed all such data in the files. As a result of this analysis, an empirical spin criterion has been formulated that can be used in design by laying out the tail surfaces for the most favorable spin-recovery characteristics. The criterion has been presented in Technical Note No. 711.

A further analysis of the data from routine tests has been made in an attempt to obtain a more complete understanding of the action of the ailerons in a spin and during the recovery. The effect of the ailerons was found to be intimately related to the mass distribution of the airplane. With a knowledge of the mass distribution, it is now possible to predict whether the ailerons should be set for or against the spin for most rapid recovery. The possibility of using the ailerons with an abnormal displacement as an antispin device has also been investigated. A paper on the subject is now in preparation.

The reliability of the information on spinning characteristics obtained from the free-spinning tunnel is a matter of some concern. The Committee, with the cooperation of the services, now receives information

on the spinning characteristics of full-scale airplanes the models of which have been previously tested in the tunnel. A comparison of considerable full-scale data with the model data indicated that the wind-tunnel data correctly predicted the full-scale spinning characteristics in 80 percent of the cases. In 10 percent of the cases, the tunnel results were conservative. In only 10 percent of the cases did the model results give an optimistic prediction of the recovery of the corresponding airplanes. Ways of improving the reliability of the tunnel are being considered.

One evident contributing factor to the difference between the model and airplane characteristics is the low scale of the model tests. The influence of scale is being studied in a limited range by comparison of two different-size models of the same airplanes.

The investigation of the relative importance of wing arrangement, tail arrangement, and mass distribution on the spinning characteristics of low-wing monoplanes, started 2 years ago, has been completed. Reports have been published dealing with the effect of changing the relative distribution of mass along the wings and the fuselage and of changing the fore-and-aft position of the center of gravity (Technical Report No. 672). A report dealing with the effect of relative density of the airplane, or its equivalent, the altitude of the spin, is in preparation. Data on the final phase of the work, the effect of a percentage change in the radii of gyration about all three axes, are now being analyzed.

#### STALLING

The investigation of the stall of an airplane and of the means of improving it has been continued. In conjunction with the investigation of flying qualities, inspection is being made of the stalling characteristics of existing airplanes. It has been found that tip stalling is not always entirely responsible for undesirable characteristics. One airplane, for example, that rolled violently when stalled with flaps up was observed to settle with some degree of lateral control when the flaps were extended, even though tuft observation showed that tip stalling was accentuated with the flaps extended. The development of the stall with the flaps extended was sufficiently symmetrical so that no large lateral disturbances occurred.

Of the airplanes tested, those that possessed strong longitudinal stability were rated by the Committee's pilots as having the best stalling characteristics. In these airplanes, where the stall was produced only as a result of a definite forceful use of the elevator control, the stall was robbed of the element of surprise. Under these conditions, the undesirable character of the stall appeared much relieved.

Despite the contributing effects of other factors as shown by the flight tests, the wing characteristics con-

tinue to remain the chief factor in the stalling problem. Several projects are in progress dealing with this phase of the problem. The investigation in the variable-density wind tunnel mentioned in last year's report to determine the relative efficiency of various methods, such as twist, change of section, and change of camber, for the prevention of tip stall is well advanced. Technical Note No. 713 has been published presenting a comparison of several tapered wings in the design of which these methods are employed to avoid tip stalling. It is concluded that for aerodynamic equality and no tip stall, ratios of tip chord to root chord of between one-third and one-half will give the lightest wings. The analysis on which the paper is based is now being extended to obtain general design charts dealing with the stalling of tapered wings. The tests to determine the spanwise progress of the stall of several representative wings with different amounts of taper and sweep have been completed, and the analysis of the results has been started.

If the stalling of the wing tip of a highly tapered wing can be delayed to a higher angle of attack than that of the center section, the lateral stability and the useful maximum lift coefficient of the wing will be greatly improved. One effective method of accomplishing this end is the incorporation of slots in the tip portion of the wing. Tests have been made in the 7- by 10-foot wind tunnel of an N. A. C. A. 23012 airfoil with and without a slotted flap to develop fixed slots that can be employed to increase the useful range of angles of attack. The results of these tests (Technical Note No. 702) show the best position of the slot to be near the leading edge of the airfoil. One arrangement of the fixed slot increased the angle of attack for maximum lift  $11^\circ$  for the plain wing and  $10^\circ$  for the wing with the slotted flap. The chief disadvantage of the fixed slot was the increase in drag at low lift coefficient.

Technical Note No. 670 has been published describing the mechanical stall-warning device discussed in the last annual report.

#### MANEUVERABILITY

The investigation of the maneuverability of Navy airplanes has been continued, and tests on the third and the fourth airplanes of the series have been completed. Originally undertaken to determine the maximum angular accelerations to which an airplane might be subjected, the investigation has now been extended to include studies of the effect of unorthodox manipulation of control stick and tabs.

Flight investigations of the maneuverability of several Army pursuit airplanes have also been completed during the past year. The results have shown that from the pilot's viewpoint maneuverability is greatly affected by the characteristics of the longitudinal control. Airplanes possessing neutral or slight longitudinal stability, and consequently very little control move-

ment to offset large changes of angle of attack, were found to be subject to inadvertent stalling in accelerated maneuvers.

#### TAKE-OFF

The important factors influencing the take-off performance of an airplane are wing loading and power loading. These factors are ordinarily prescribed by the high-speed flight condition and cannot be modified to decrease the take-off run. Consequently, the most practical solution to the problem of improving take-off performance appears to lie either in the development of better high-lift devices for use during take-off or in the improvement of the characteristics of propellers operating under take-off conditions.

During the past year the Committee has conducted two propeller investigations that provide data having a direct bearing on the take-off problem. The results of the first of these investigations, published in Technical Report No. 650, include data from tests of full-scale propellers in the propeller-research tunnel indicating the effect of airfoil section on take-off efficiency. The second investigation, which was made on the special static-thrust apparatus mentioned last year, supplied data on the static thrust of full-scale propellers. These data should prove useful in estimating the distance required for take-off.

#### LANDING

The investigation of the landing characteristics of airplanes to obtain statistical information on the vertical velocities and accelerations in landings has been continued. The evaluation of the data obtained in the tests mentioned in the last annual report has been completed, and the results have been reported to the Army Air Corps and to the Bureau of Aeronautics, Navy Department. Tests of four additional airplanes, including one equipped with a tricycle landing gear, have been made. The results for three of these airplanes have already been reported to the Civil Aeronautics Authority, the Army Air Corps, and the Bureau of Aeronautics, Navy Department. A number of one-wheel landings were included in the tests of one airplane to obtain information concerning the effect of the lateral landing attitude of the airplane with respect to the landing surface upon the maximum loads sustained by the landing gear.

In addition to landing tests involving conventional landings, an investigation has been made of vertical velocities and attitudes and of the resulting landing-gear loads encountered in blind or instrument landings of Army bombers of two different types. The results obtained with one type of bomber have been reported to the Army Air Corps and a report on the results for the other type has been prepared. The maximum vertical velocities in such landings were found to be twice as great as the maximum values for normal landings.

The results of the landing tests made thus far with airplanes equipped with tricycle landing gears have indicated that the maximum nose-wheel loads are likely to be encountered in approximately three-point landings. Nose-wheel loads encountered in two-point landings, wherein the airplane pitches forward after impact on the main wheels, are not likely to be critical.

By use of the apparatus mentioned in the last annual report, tests have been conducted for the purpose of determining the friction required to prevent the shimmy of a castering wheel. Various wheels and tires were tested under varying loads and with varying caster lengths and spindle angles. One interesting feature of the results was that they indicated the desirability of making the inclination of the spindle small. A report presenting the results of these tests is being prepared for publication.

The investigation of ground effect by means of a glider towed by an automobile, which was mentioned in the last annual report, has been completed and the results are being prepared for publication. For most of the conditions tested, which included full-span flaps, the agreement between the experimental results and the ground-effect theory, as regards effects on angle of attack and drag, was reasonably good.

Tests to determine the ground effect on the aerodynamic characteristics of rectangular and tapered wings, both with and without split and slotted flaps, have also been made in the 7- by 10-foot wind tunnel. In these tests the ground was simulated by the use of a plane located various distances from the model. It was found (Technical Note No. 705) that the ground effect on wings with flaps is a marked decrease in drag, a decrease in diving moment, and a substantial reduction in maximum lift.

#### AIRFOILS

**Section characteristics.**—In the last annual report there was considerable discussion of attempts to correlate and reconcile the airfoil data obtained from various sources. Methods of correcting the standard characteristics of airfoil sections determined from tests in the variable-density wind tunnel to allow for turbulence, strut interference, and other features had been evaluated, and the results were published in Technical Report No. 669. In spite of these efforts, however, the situation was unsatisfactory and new methods of making airfoil studies seemed necessary. The presence of turbulence in wind-tunnel air streams had long been a source of trouble and uncertainty and the transition from laminar to turbulent flow was known to be affected by this turbulence in the stream.

At the same time, increasing knowledge of boundary-layer phenomena had given strong indications of the possibility of more extensive laminar boundary

layers and consequent lower drags than have been available with conventional airfoil sections. At least two facts were outstanding: First, airfoils should be designed to take advantage of true low-drag laminar boundary layers over a greater portion of the airfoil; and, second, a nonturbulent air stream as nearly comparable as possible with free-air conditions should be provided to test the new airfoil shapes.

The procurement of such equipment was begun some time ago by the Committee and about a year ago a low-turbulence wind tunnel became available. This tunnel, which is somewhat unusual in design, has a test section 3 by 7½ feet, and is arranged for the testing of large models having chords of several feet and only 3-foot span in essentially two-dimensional flow. The usual methods of measuring the stream turbulence were not considered sufficiently sensitive; direct comparisons of transition on airfoils from measurements in flight, in the new wind tunnel, and in other tunnels, were therefore made. The turbulence level of the new tunnel was found to be well below the level of other wind tunnels of the Committee; nevertheless, it seemed improbable that the desired effective zero turbulence had been attained. It was considered sufficiently low, however, pending more reliable comparisons with flight, to justify some preliminary investigations.

These preliminary investigations were started by the development of new airfoil forms that, when tested in the new equipment, immediately gave drag coefficients of one-third to one-half the values obtained for conventional sections. These studies have been extended to the 8-foot high-speed tunnel and to flight with substantial agreement as to the possibilities of the new airfoils. This work is being continued both in flight and in the low-turbulence tunnel. Extension of this work into the field of compressible flow is being carried on in the 24-inch and 8-foot high-speed wind tunnels.

**Wing characteristics.**—The calculation of wing characteristics has been continued, and the methods and results of comparisons with tests which included wings with partial-span flaps have been presented in Technical Report No. 665. It now seems that the knowledge of the section characteristics is sufficient to make possible the determination, with an accuracy sufficient for many practical purposes, of the important wing characteristics for any particular wing design. Efforts in airfoil work may now be concentrated on the determination of accurate section characteristics.

**Surface roughness.**—The results of tests mentioned in the 1937 annual report showing the effects on wing drag of countersunk and protruding rivet heads, of spot welds, of several types of lapped joints, of surface roughness, and of manufacturing irregularities have been supplemented by data from additional tests and

published in Technical Note No. 695. This note suggests a method of estimating the effects of rivet heads and lapped joints for conditions outside the range of the tests with respect to Reynolds Number or rivet and lap size and arrangement. The method depends on estimating separately the drag increments due to premature transition and to the direct drag of the irregularities. As an example, it is shown that a typical arrangement of rivets and lapped joints on the rear 75 percent of the wing of a large airplane which has a total wing area of 3,600 square feet flying at 250 miles per hour will increase the drag sufficiently to require 180 horsepower more than would be necessary if the wing were smooth.

Additional irregularities investigated have included surface waviness and rib stitching. (See Technical Note No. 724.) The results of the tests of waviness may be simply summarized. Small waves such as occur on wings made according to present standards of workmanship will not seriously increase the drag unless they precipitate premature transition or premature compressibility effects; that is, unless they occur on the forward part of the wing. A single wave only 0.020 inch high and 8 inches wide located 10.5 percent of the chord from the leading edge of an N. A. C. A. 23012 airfoil was sufficient to cause transition to occur at the wave with a consequent drag increase. Rib stitching corresponding to a rib spacing of 6 inches increased the drag 7 percent; the drag increment was proportional to the number of ribs for larger rib spacings. About one-third of the drag increase was due to the premature occurrence of transition at the forward ends of the stitching.

#### AERODYNAMIC INTERFERENCE

For several years the Committee has been conducting in the variable-density wind tunnel a general investigation of fundamental character into the aerodynamic interference between the component parts of airplanes. The initial part of the investigation, described in Technical Report No. 540, comprised tests of 209 combinations of wing and fuselage, in which the variables studied included form of wing, shape of fuselage, position of wing relative to fuselage, and form of wing-fuselage juncture. Subsequent reports dealt with more complete investigations of the same variables and with an extension of the program to study the interference associated with tail surfaces added to wing-fuselage combinations (Technical Report No. 678). The general investigation is now nearing completion with a program of tests of nacelles in combination with a round fuselage, a tapered wing, and conventional arrangement of semielliptical tail surfaces. Two sizes

of streamline nacelles and one of conventionally cowed nacelles are being investigated. Although the program is not yet completed, the results thus far indicate that the adverse interference of streamline nacelles of moderate size on the maximum lift is difficult to control. Further, the drag increase is appreciable and strengthens the conclusion that high-performance airplanes should comprise the minimum number of efficient component parts, efficiently combined. It is therefore desirable that nacelles be eliminated in airplane design.

An extensive investigation of a similar nature but including also the effects of propellers is in progress in the full-scale wind tunnel. An investigation is now under way on a complete airplane model for the purpose of evaluating the effects of air-cooled engine nacelles of the conventional type with N. A. C. A. cowlings over a large range of design conditions. The sizes and numbers of nacelles correspond to arrangements on large four-engine and small high-powered two-engine airplanes. The ratio of nacelle diameter to wing thickness is varied from 0.5 to nearly 4.0 and the position of the nacelles is varied relative to the wing chord line and the leading edge. A study is being made of the nacelle drag, the propulsive efficiency, and the effects of the nacelles on the pitching moment and the maximum lift coefficients of the model.

In the 20-foot wind tunnel, further tests have been made of wing-nacelle-propeller combinations. The first series of tests dealt with the effect of nacelle-propeller diameter ratio on body interference (Technical Report No. 680). This investigation was followed by tests of several model nacelle-propeller arrangements in front of an N. A. C. A. 23018 wing. Data were obtained on the internal air flow, the drag, the interference drag, and the propulsive efficiency. The results, which will be published soon, are in accord with those of earlier investigations.

Supplementing tests of a few years ago, in which the drag of normal landing gears was determined, an investigation has been made in the 20-foot tunnel to determine the drag of the nose-wheel component of tricycle landing gears. The variables studied included size of wheel, form of supporting struts, form of fairing, position of nose wheel with respect to the fuselage, and degree of wheel retraction within the fuselage. For the partly retracted condition, no material reduction in drag below that of the completely exposed gear was noted except when the nose wheel was halfway retracted into the very nose of the fuselage. In this condition the gear drag was negligible.

Another extension of the interference research dealing with the effects of compressibility is considered under the subject of compressibility effects.



## COMPRESSIBILITY EFFECTS

Technical Report No. 646 has made available a large amount of information on the nature of compressible-flow phenomena. As a result of this fundamental work, conducted in the 24-inch high-speed wind tunnel, and a study of the information gained as it may affect actual designs of high-speed airplanes, it appears that the propeller will offer the most serious problems. Other parts of the airplanes may be so designed as to avoid serious compressibility losses. The propeller problem is the most serious because the propeller operates at higher relative air speeds than the other parts of the airplane and because its efficiency is decreased by the relatively large section thicknesses commonly used near the blade roots.

At present, therefore, the greatest emphasis is being placed on the development of suitable blade sections for high-speed propellers. Based largely on the data presented in Technical Report No. 646, new sections have been designed and experiments are being conducted in the 24-inch high-speed wind tunnel. Tests already made show that considerable improvement may be obtained. Meanwhile, further fundamental investigations to study the nature of compressible-flow phenomena, particularly at and near the critical speed, are being conducted in the 11-inch high-speed wind tunnel.

It is important to understand, however, that considerable care must be exercised in the design of other components of the high-speed airplane. An investigation in the 8-foot high-speed wind tunnel of a model of a typical transport airplane illustrates two important sources of difficulty: First, misalignment of nacelles having N. A. C. A. radial-engine cowlings with the air flow may result in important decreases of the nacelle critical speed; second, mutual interference between the parts of an airplane may reduce its critical speed below that of any of the individual parts when tested separately. In the case of the transport model investigated, the critical speed of the nacelles was 30 miles per hour lower than the critical speed of the same nacelles isolated from all the other parts of the airplane except the wing. Similar effects must be considered when any two or more basic shapes are combined.

## PROPELLERS AND PROPELLER-BLADE SECTIONS

An extensive program of propeller research conducted in the propeller-research tunnel has been concluded. A large portion of this work has been described in previous reports. Technical Report No. 650, dealing with tests of propellers having different blade sections, and Technical Report No. 658, dealing with tests of propellers having different pitch distribution, have been published during the year. Differ-

ences of 3 percent in maximum efficiency were found for the propellers having different blade sections. Differences in take-off efficiency were much larger. The effects of changes in pitch distribution appeared to be small. It is important to note, however, that at very high blade angles the use of a spinner materially increased the maximum efficiency. The concluding report of this series, yet to be published, deals with an investigation of static thrust conducted on a special outdoor test rig.

Force tests were conducted on three full-scale propellers in conjunction with the more streamlined afterbody mentioned in the discussion of cowlings research. Comparisons were made with a streamline nose and an open-nose cowlings in front of the better afterbody. The results of these tests are being analyzed on the basis of the preceding propeller data and a report is being prepared presenting this information.

Sufficient data are now available so that a fair approximation to the efficiency and power absorbed can be made in the usual cases. It has been noted, however, that peculiar disturbances occur with some cowlings forms and it has been impossible to predict these in advance, so that anomalous efficiencies may be expected in some cases. The poor efficiencies often calculated from flight tests as compared with wind-tunnel results have now been quite conclusively proved to be really an effect of reduced horsepower output. The installation of dynamometers on engines in flight has settled this question and more extensive use of this apparatus may be expected.

The present knowledge of propeller art and the increasing speeds and power to be expected with aircraft likely to be developed in the near future indicate that serious propeller problems may be expected. The limitation in tip speed imposed by compressibility phenomena is of increasing importance because actual aircraft speeds will soon be nearly as great as present propeller critical tip speeds. Important design compromises may be necessary to avoid serious compressibility losses. Such compromises may lead to decreased efficiency unless extreme care is used in design. Solidity higher than any values heretofore used is indicated because of tip-speed limitation and increased engine power. Increasing speeds will lead to very high pitch settings so that rotation losses will become important. Considerable study has been given the problem and, as a result, a program of blade-section development is being conducted in the 24-inch high-speed wind tunnel to lead to the development of blade sections that will have higher critical speeds and decreased drag.

As the data become available, the results are being analyzed to study the application to the design of optimum propellers for high-speed aircraft. Work is



now proceeding on the design of a family of propellers having the best blade sections obtainable to reduce the blade drag and compressibility losses and having thrust distribution designed to attain minimum induced loss. The range of solidity has been increased to include the extreme values likely to be encountered. An investigation of counterrotating propellers conducted at Stanford University and financed by the Committee indicates important increases in efficiency likely at high pitch settings. Further study will be made so that good propeller efficiency may be maintained through the elimination of the large rotation loss that occurs at high pitch settings.

An analysis of the operation of the propeller by the use of the distribution of the thrust and torque along the blades combined with theoretical equations has been made. The data for the analysis were obtained in the N. A. C. A. 20-foot wind tunnel on a 2-blade propeller of 4-foot diameter operating in front of four body shapes ranging from a small shaft to support the propeller to a conventional N. A. C. A. cowling. A method of estimating the axial and rotational energy in the wake as a fractional part of the propeller power is given. The average angle of twist in the propeller slipstream is shown to be a function of the torque coefficient  $Q_c$  and charts are given to aid in estimating the angle. Counterrotating propellers are shown to be attractive from considerations of aerodynamic efficiency when the propellers are highly loaded. A report on this work is in the process of publication. Similar work was conducted on two full-scale propellers differing only in pitch distribution along the blades. A report is being prepared on this work.

#### COWLING AND COOLING

**General conditions.**—For several years it has become increasingly apparent that better solutions for the cowling and cooling problems are required to meet the demands of the military services for increased airplane performances. Work is still in progress dealing with the development and improvement of the N. A. C. A. cowling, but it now appears that marked advances are at hand through the application of fundamental aerodynamic principles to the problems of cooling.

The present approach to the subject considers the problem divided into two separate ones: The internal-cooling problem; and the residual problem having to do with the scoop, vent, duct, and external-flow conditions. The internal cooling is chiefly a problem of heat transfer from the cylinder or radiator. Considerable progress has been made toward the desired objective of this phase of the problem—to minimize the quantity of air required and to minimize the local internal work of cooling. This internal work, the product of the pres-

sure drop across the cooling unit by the volume per second of air employed, is of fundamental importance because it represents a power-loss increment associated with the heat-transfer mechanism.

The external-flow phase of the problem is approached by considering this power-loss increment and air quantity as specified and then attempting to minimize the resulting power loss associated with the complete system. A certain power-recovery increment may fortunately be associated with the thermodynamic cycle of the cooling system (Meredith effect).

Energy from the propeller slipstream should be readily available. One of the most promising systems of this type, which has been under investigation in the propeller-research and the full-scale tunnels during the year, employs openings in the leading edge of the wing in the propeller slipstream. Other systems, however, may represent a close approach to the ideal, including the wing-duct systems investigated in the 7- by 10-foot tunnel and the full-scale tunnel and also certain applications of the N. A. C. A. cowling under investigation in the 8-foot high-speed tunnel. The results already obtained with several of these systems suggest that, with careful aerodynamic design of the inlet and outlet openings and the internal-duct systems, a close approach to the ideal performance of these units may be realized. It thus appears that practical systems are within reach for which the power recovery may exceed the power loss and that, for high-performance airplanes, the cooling system may become an asset rather than a liability.

It should be emphasized, however, that high-performance systems must be of fundamentally correct design. Many tests of modern pursuit-type airplanes in the full-scale tunnel have shown large drag losses associated with the cooling and scoop systems commonly employed. Moreover, the difficulties can seldom be adequately corrected because the original design did not include adequate provisions for a fundamentally correct cooling system.

**Cowling research.**—The study of the pressure available for ground cooling in front of the cowling of an air-cooled engine discussed in the last annual report is described in Technical Note No. 673. The design report on cowling for radial air-cooled engines is presented in Technical Report No. 662.

The results of flight tests of four designs of nose-slot cowlings with several variations in each design are presented in Technical Note No. 720. The results describe the development of the nose-slot cowling from flight data. A sample design calculation involving the use of results from flight, wind tunnel, and ground tests is given in an appendix to illustrate the design procedure.

An investigation of full-scale nose-slot cowlings has been conducted in the 20-foot wind tunnel. Engine conductivities from 0 to 0.80 were investigated. Two basic nose shapes were tested to determine the effect of radius of curvature of the nose contour; with the nose shape with the smaller radius of curvature the higher pressure drop across the engine was obtained. The best axial location of the slot for low-speed operation was found to be in the region of maximum negative pressure for the basic shape for the particular operating condition. The effect of the propeller operating condition on the available cooling pressure was determined. The maximum nondimensional pressure drop obtained for the high-speed condition with an engine conductivity equivalent to that of a modern double-row radial engine and a propeller with good blade sections near the hub was 1.45 and for the take-off condition, 3.75. For the propeller with a round blade shank, the values were 1.23 and 1.65, respectively. A report on this work is in the process of publication.

The drag and the power cost associated with the changing of the nose of a nacelle from a streamline shape to a conventional N. A. C. A. cowling shape was investigated in the 20-foot wind tunnel. Full-scale propellers and nacelles were used. The increment of drag associated with the change of nose shape was found to be critically dependent on the afterbody of the nacelle. Two streamline afterbodies were tested. The results of the tests with the more streamlined afterbody showed that the drag approached that of an airship form and that the added drag due to the open-nose cowling was only one-fourth of the drag increase obtained with the other afterbody.

From the experience gained in the investigation of the nose-slot cowling, it was found that the cowling exit would work efficiently if the after part of the body allowed the air to flow smoothly without breakdown of flow in that region. If the shape of the exit allowed breakdown of flow to occur, the slot created high drag and very low available pressure drop across the baffles. From a consideration of the available pressure behind the propeller, it was believed that, if a good exit slot design were used, much higher available pressure drops could be obtained by the use of cowling flaps than is usually supposed. Tests were therefore made to determine the available pressure drop for cowling flaps, care being taken to provide good flow conditions at the exit slot. The pressure drop available for cooling with a conductivity equivalent to that of a double-row radial engine was found to be 4.85 for the take-off condition for a propeller of good blade section and to be 3.17 for the propeller with round blade shank. A report on this work is being prepared.

An investigation in which blowers of various forms were used, in particular in the inlet passage of a modi-

fied N. A. C. A. cowling, has been made both on models in the propeller-research tunnel and in flight. Although the blower absorbs some power, it is evident that there is a definite advantage in reduced drag, in higher propeller efficiency because of the covering of the hub, and in greatly improved cooling. In one case it has been possible to run the engine continuously on the ground with much lower (85° to 100° F.) temperatures than were obtained in flight with a normal cowling. Ground cooling is of importance in some types of aircraft and better cooling at higher speeds with large engines is necessary. Several reports have been prepared discussing various phases of the problem, and the investigation is being continued.

**Wing-duct radiators.**—As an extension of the investigation conducted in the 7- by 10-foot wind tunnel on full-span cooling ducts, tests have been made in the full-scale wind tunnel of similar ducts of finite span in a large wing for the purpose of evaluating end effects and investigating the scale effect on the characteristics of the ducts. In the investigation in the full-scale wind tunnel, a special study was made of means for regulating the quantity of air flow for the various flight conditions, particularly in regard to obtaining sufficient cooling air for the climb condition without an excessive amount for the high-speed condition, which would result in a serious penalty in drag.

The ducts of the more efficient types were found to affect inappreciably the maximum lift coefficient of the wing. Tests with operating propellers in front of the ducts indicated that ground cooling would be satisfactory and that in the climb, if the radiator inlet was placed behind the upgoing propeller blades, the cooling-air quantity would be increased about 10 percent. Tests conducted with heat applied to the radiator element indicated that some recovery of the energy lost in cooling is possible.

#### WINDSHIELDS

A systematic series of windshields, of both the transport and the closed-cockpit types, was tested in the 8-foot high-speed wind tunnel to indicate the drag of conventional types and to determine how these conventional types can be improved. It appeared that a typical transport-type windshield might account for about 21 percent of the fuselage drag but that it should be practicable to construct a windshield, with either single-curved or double-curved glass, that would account for only about 2 percent of the fuselage drag. It also appeared that recessed windows should be avoided.

Typical closed-cockpit windshield (including canopy), such as are used on small fighting airplanes, in some cases appeared to account for 15 percent of the drag of the entire airplane, but by improved design the windshield drag should be almost eliminated.

## THEORETICAL AERODYNAMICS

**Normal-force and pressure distribution over airfoils.**—A relatively exact and simple method for the prediction of the chordwise normal-force distribution over an airfoil was developed by the Committee in 1938. As mentioned in the last annual report, this method is applicable to ordinary airfoils and to airfoils equipped with plain, split, or serially hinged trailing-edge flaps. The pressures acting on the upper and the lower surfaces of the airfoils, however, are not separately determined by this method. A method of determining these individual pressures has been described in a report recently published (Technical Note No. 708). This method permits the determination of the pressure distribution over an airfoil section when the normal-force distribution (from Technical Reports Nos. 631 and 634) and the pressure-coefficient distribution over the "base profile" (that is, the profile of the same airfoil if the camber line were straight and the resulting airfoil at zero angle of attack) are known. Distributions of the base-profile pressure coefficients for the usual N. A. C. A. family of airfoils, which are also suitable for several other commonly employed airfoils, are included in Technical Note No. 708.

**Compressibility effects.**—Theoretical investigations of the effect of compressibility on the flow past obstacles have been continued. In particular, the effect of compressibility on the moment of an arbitrary shape has been obtained and the general formulas have been applied both to elliptic cylinders and to symmetrical Joukowski profiles. The results of this investigation have been presented in Technical Report No. 671.

**Span load distribution on wings.**—A simple method of successive approximation for determining the span load distribution on wings has recently been developed by the Committee and the results published in Technical Note No. 732. A straightforward arithmetical procedure is described in which component loads are added to form the distribution sought. The proportions, the magnitudes, and the relative spanwise positions of these component loads are determined from equations derived from the differences between the given chord distribution and the chord distributions associated with the components themselves. The method is comparatively rapid and should prove useful in problems for which the span load distributions cannot otherwise be readily determined.

## WIND-TUNNEL CORRECTIONS

**Profile-drag measurements by momentum method in full-scale wind tunnel and in flight.**—The accurate measurement of the profile drag of a wing by means of surveys of dynamic and static pressure in its wake is of importance because it makes possible the evaluation of the drag of various types of protuberance on the wing and, by comparison with known characteristics of

aerodynamically smooth wings of the same dimensions, the evaluation of the drag caused by surface roughness and manufacturing irregularities. In order to investigate the accuracy of this method and the reduction of the test data by the Jones and the Betz equations, wake surveys and force tests were made in the full-scale wind tunnel on three symmetrical airfoils of different thicknesses. An analysis of the results as presented in Technical Report No. 660 shows that, for zero-lift condition, the profile-drag coefficients reduced by either the Jones or Betz equations agree with the force-test results within 2 percent. For the lifting airfoil, the error resulting from the induced field did not exceed 2.5 percent up to a lift coefficient of 1.0 and outward to a spanwise position of about 0.8 of the semispan.

The effects of turbulence present in the jet of the full-scale wind tunnel were determined by comparative velocity surveys in the boundary layer and wake momentum measurements of a polished section of a wing on an airplane in flight and in the tunnel. The results of the boundary-layer velocity measurements (presented in Technical Note No. 693) show that the end of the transition from laminar to turbulent flow occurs at approximately the same position in flight and in the tunnel but that the transition region as measured in the tunnel is somewhat broader than for flight. This difference in the boundary layer, however, accounts for an increase of only 0.0001 in the profile-drag coefficient as determined by the momentum method over the values obtained in flight.

**The 8-foot high-speed wind tunnel.**—An investigation of N. A. C. A. 0012 airfoil of 5-foot chord has been made in the 8-foot high-speed wind tunnel, which has a circular jet and a closed throat, to establish the spanwise variation of constriction caused by the presence of the airfoil. The results of this investigation will be used to determine the magnitude of the corrections to be applied to the results of later airfoil investigations.

## EFFECTS OF ICE FORMATION AND ITS PREVENTION

**Adhesion of ice to surfaces.**—In the development of methods of preventing ice formation on aircraft parts, it is important to know the force with which ice adheres to various materials. From the magnitude of this force, recommendations can be made as to lines of development that should be followed to perfect a satisfactory de-icing mechanism. An investigation was made on the adhesion of ice to various materials and the results have been published in Technical Note No. 728. The procedure consisted in freezing water onto a block of the material to be tested and then determining the force required to remove the ice. Brass, copper, duralumin, stainless steel, glass, and micarta were tested. With the exception of micarta, the adhesion

force holding the ice to the block was greater than the cohesive force within the ice itself. In each case, the ice failed at a tension of about 140 pounds per square inch leaving ice adhered to the surface. With the micarta the ice failed irregularly at a loading of 53 pounds but remained adhered to the micarta block in sections of the surface.

The tests indicated that ice will adhere to any solid surface with a force so great as to eliminate the possibility of removing the ice by mechanical means suitable for aircraft. When rubber or a thin sheet of duralumin was used, the ice could be removed with a much lower force because of the "peeling" action that took place.

The tests showed that if a liquid interface were maintained between the ice and the solid surface the ice was easily removed. In this case the force to be overcome was chiefly that exerted by atmospheric pressure. With greases, the force was somewhat greater. The analysis indicated that the commercial de-icing pastes essentially consisted of a freezing-point depressor combined with a substance to form a paste.

**Adhesion of ice to aircraft parts.**—In the ice-research program announced in the last annual report, chemical, heat, and mechanical means of ice prevention have been investigated. Attention has been given to the prevention and removal of ice from the airplane wing, the struts, the propeller, and the windshield. Under the existing program, attempts will be made to determine means for the protection of other parts of the airplane.

Flight tests in simulated icing conditions made with the inflatable-type wing de-icer indicated that only partial ice removal is possible by this method with present equipment. Residual ice accretions were observed on the leading-edge and the cap-strip regions of the de-icer. Tests to determine profile drag and maximum lift in flight have also been made on a wing equipped with a de-icer. Coefficients of profile drag and maximum lift were determined for the plain wing without the de-icer, with the de-icer free from ice accretions, and with several other drag conditions produced by attaching simulated ice formations to the regions of the wing leading edge and the de-icer cap strip. Formations on the de-icer cap strips were shown to have a very undesirable effect on the profile drag and the maximum lift.

An analysis of the results of the preliminary investigations conducted in the ice tunnel on the use of exhaust-gas heat for the prevention of ice on the airplane wings (Technical Note No. 712) indicated that a reasonably small percentage of the exhaust thermal energy will prevent the formation of ice on the wings. This work is being continued in analytical investigations and model tests both in flight and in the ice tunnel. The investigation of the use of steam heat in flight gave

results similar to those from tests made with direct exhaust heat in the ice tunnel and indicated that the quantity of heat required for ice protection was not excessive. Investigations on the use of steam have been temporarily discontinued and emphasis is being placed on tests of direct exhaust heat, which seems to require less mechanical equipment than does steam.

The investigations of chemicals applied prior to flight for the prevention of ice on the airplane wing have been continued, although no satisfactory substance has been found when tested under simulated icing conditions. Alcohols and mixtures of alcohol and glycerin were discharged through perforations along the leading-edge region of a wing. In these tests the perforated surface and the distribution tube were attached to the surface of an inflatable de-icer. Tests conducted with and without the de-icer in operation failed to prevent or remove ice from the wing. A similar investigation with ethylene glycol and a mixture of ethylene glycol and isopropyl alcohol was made on a small strut such as might be used for an antenna mast. The discharged fluid prevented the formation of ice although the quantity required seemed to be excessive.

The distribution pattern of ice-inhibiting fluids over the blades of a propeller of large diameter has been studied in flight. The results indicate (Technical Note No. 727) that ducts or channels along the leading edge of the propeller blade will be required to distribute properly ice-inhibiting fluid on propellers of large diameter. Further studies are planned on the problem of preventing ice formation on the airplane propeller.

An investigation has been made of several methods of preventing ice on the airplane windshield. Models equipped for the application of electric heat and of heated air, and a rotating wiper blade that dispenses alcohol from its center have been tested. Ice was prevented on each of the model test panels when subjected to simulated icing conditions in flight. Air heated by the exhaust to a temperature of about 170° F. and passed through a  $\frac{1}{8}$ -inch gap between two panes of glass with a velocity of 50 feet per second prevented the formation of ice during very severe simulated icing conditions. This method seems to offer the simplest solution to the problem of windshield icing since it prevents ice on both sides of the glass, requires no moving parts, and utilizes what is otherwise waste energy.

#### ROTATING-WING AIRCRAFT

The possibility of improving the lift-drag ratio of rotors of rotating-wing aircraft in forward flight by retarding or preventing the stalling of the inboard elements of the retreating blades is being investigated. A preliminary step in this investigation was to supplement theoretical calculations of the operating condi-

tions of blade elements in various parts of the disk with photographic observations of the behavior of silk tufts mounted on the blades of a YG-1B autogiro. The tuft observations indicated that the portion of the rotor disk in which the elements are stalled is somewhat larger than would be expected from theoretical considerations. A technical note presenting the results of the initial observations is being prepared and additional observations on blades of various airfoil section and plan form are in progress.

An attempt is being made to isolate the factors in the design of rotor hubs and blades that are responsible for the severe vibration present in the control systems of present-day direct-control autogiros. To this end, the varying loads in the control system of a YG-1B autogiro have been recorded in flight at various air speeds. Analysis of the records indicates that mass unbalance or improper matching of the blades is not responsible for the control vibration in this machine and that some modification of hub and blades may be desirable. Similar tests on the same machine equipped with blades of improved design are now in progress.

Data on the blade motion and the control characteristics of nonarticulated feathering rotors have been obtained from flight tests of the Wilford XOZ-1 sea gyroplane and are being evaluated.

#### DETERMINATION OF MOMENTS OF INERTIA

In the determination of the moments of inertia of airplanes by swinging tests, the effect of the ambient air in increasing the apparent mass and moment of inertia must be estimated. Such estimates are chiefly based upon experimental data on the additional mass and moments of inertia of flat plates. During the past year it has been necessary to supplement previously estimated values of the moments of inertia of airplanes by data obtained from experiments with flat plates of tapered plan form. These experiments were conducted in a vacuum chamber and the results are now being prepared for publication.

#### MISCELLANEOUS TESTS OF MODELS AND AIRPLANES

A considerable number of requests have been received from the Army and the Navy during the past year for investigation of complete models of military airplanes and experimental airplanes of the fighter class in the Committee's wind tunnels. Most of the models have been investigated at the request of the military services; some models have been tested for manufacturers at their expense and other models have been built and tested in connection with the Committee's own research programs. The work has been carried out in the full-scale, the 20-foot, the 7- by 10-foot, and the 8-foot high-speed wind tunnels.

The greater portion of the time in the full-scale tunnel has been devoted to tests for the Army and Navy of complete models and single- and two-place airplanes of the combat type. The information obtained in the model tests has resulted in definite improvement of the design of the projected airplanes. The modifications made to airplanes in these tests have indicated substantial increases in the high speed, and these increases have been verified by flight tests.

Investigation of a model of a typical two-engine low-wing transport has been made in the 8-foot high-speed wind tunnel. The investigation has shown the contributions of various components of the airplane model to the total drag. The wing accounted for about 37 percent of the total drag; the fuselage, including interference, 25 percent; the nacelles, 11 percent; and the landing wheels with the main wheels retracted but partly projecting below the nacelles, 14 percent. The landing wheels even in the retracted position contributed a notably large percentage of the total drag. This drag could be eliminated by complete retraction. About 80 percent of the total landing-gear drag was due to the main wheels and the remainder to the tail wheel. The nacelles were the only part of the airplane exhibiting marked compressibility effects at speeds up to 450 miles per hour. The critical speed of the nacelles could have been increased to above 450 miles per hour by proper alinement with the air stream. The results of this investigation are now being prepared for publication.

Aerodynamic tests of five side-float models for seaplanes were made in the 7- by 10-foot wind tunnel and the results have been published in Technical Note No. 680. This investigation indicated that the most promising method of reducing the drag of these floats is to lower the angle at which the floats are rigged.

#### NATIONAL BUREAU OF STANDARDS

##### WIND-TUNNEL INVESTIGATIONS

The aerodynamic activities of the National Bureau of Standards have been conducted in cooperation with the National Advisory Committee for Aeronautics.

Wind-tunnel turbulence.—The great progress in the study of the practical effects of turbulence in wind tunnels as related to performance in flight carried out at Langley Field has shifted the interest from the effects of intensities of turbulence of the order of 1 percent to those of intensities of the order of 0.1 percent. As a result, it has been necessary to provide wind-tunnel equipment in which low turbulence levels can be obtained and to increase the sensitivity of the apparatus for measuring turbulence.

The modernization of the 4½-foot wind tunnel provided an air stream of low turbulence. Since this tun-

nel was first placed in operation in October 1938, numerous improvements have been made, each one successively reducing the turbulence of the stream, and further reductions are in prospect as the sources and behavior of wind tunnel turbulence are better understood.

The intensity of the turbulence is so low that its measurement presents some difficulties. However, by the use of a Wollaston wire about 0.00024 inch in diameter and 0.16 inch in length, sufficient sensitivity is obtained to measure intensities as low as 0.05 percent with reasonable precision. It is found necessary to use an antivibration support, and to modify the wire mounting to prevent vibration of the wire itself and to insure vibration of the mounting prongs as a unit when mechanical shock occurs.

The diameter of these small wires cannot be measured with sufficient accuracy to permit a computation of the time constant. Apparatus was constructed for experimental determination of the time constant. The method used is that of vibrating the wire with a fixed velocity amplitude but varying frequency in a stream of low turbulence. The vibrator is an electromagnetic pulsator and the velocity amplitude is measured by an electromagnetic pick-up device. Reproducible and accurate results are obtained.

The great progress in the development of electron tubes, the feed-back amplifier, voltage-stabilizing circuits, etc., has made possible for the first time the design of really portable equipment for measuring turbulence. With suitable hot-wire units, both longitudinal and transverse components of the fluctuations can be measured, as well as the correlation between longitudinal and transverse components. Construction of amplifier and power supply have been completed and their operating characteristics are under study. The design makes possible the use of the condenser-type compensating circuit, permitting a considerable reduction in the weight and size of this component.

A general account of turbulence investigations conducted for the Committee at the National Bureau of Standards was presented at the Fifth International Congress for Applied Mechanics.

**Boundary-layer investigations.**—A report entitled "Air Flow in the Boundary Layer of an Elliptic Cylinder" was published by the Committee as Technical Report No. 652.

The study of transition at low turbulence levels on a thin flat plate parallel to the wind direction has been in progress during the year. In view of the results of previous work, great care has been taken to have all factors which might affect the transition under control. The plate, which is made of aluminum and is  $\frac{1}{4}$  inch thick and 12 feet long, is placed vertically between opposite faces of the octagonal working section of the tunnel. The leading edge was carefully machined to a lenticular form with a very thin edge.

The pressure gradient is adjustable by means of flexible side plates on the two vertical faces of the octagonal test section, making in effect a channel on each side of the plate of adjustable width. The pressure could be adjusted to be constant within 0.05 percent of the velocity pressure.

A number of exploratory measurements of the location of transition as a function of various factors have been made. Contrary to expectation, the transition point is not unduly erratic or sensitive to small changes. Its location still depends markedly on the turbulence and erratic variations in its position obtained in other laboratories are probably due to erratic variations in the turbulence level. A value of the critical Reynolds Number of about 3,000,000 has been obtained for the condition of zero pressure gradient.

The work conducted for the Committee formed the basis of the Second Wright Brothers Lecture of the Institute of the Aeronautical Sciences.

#### AERONAUTIC-INSTRUMENT INVESTIGATIONS

The work on aeronautic instruments has been conducted in cooperation with the National Advisory Committee for Aeronautics and the Bureau of Aeronautics of the Navy Department.

**Investigations.**—A description of, and laboratory performance data on, the gyroscopic turn indicator, the directional gyroscope, the gyro horizon, the gyromagnetic compass, and a description only of the automatic pilot, are included in a report published as Technical Note No. 662.

A report on the theory and performance of modern rate-of-climb indicators has been published as Technical Report No. 666.

The investigation of corrugated diaphragms in progress included measurements of the central deflection against differential pressure of geometrically similar diaphragms of four diameters (1.5, 2, 2.5, and 3 inches) and a number of thicknesses in the range from 0.001 to 0.013 inch. The data were obtained principally on beryllium-copper and phosphor-bronze diaphragms and on a few diaphragms of Z nickel. These data have been analyzed and generalized into a mathematical formula. A report has been completed.

A sensitive diaphragm capsule has been developed which is prevented from deflecting above any desired differential pressure. At the cut-off pressure the diaphragms nest into each other. Two elements, consisting of two evacuated capsules, have been built for measuring air pressure in the range from 140 to 0 millibars. When used on a Diamond-Hinman radio sonde a sevenfold increase in sensitivity was secured in this pressure range.

The theory for the movement of a piston in a cylinder filled with liquid has been formulated in connection with an investigation of dashpots. To check the theory,



eighteen pistons were tested in cylinders of two diameters. Liquids of two viscosities were used. The piston clearance was varied from 0.0005 to 0.005 inch. Theory and experiment checked within  $\pm 10$  percent. A report is being prepared.

#### SUBCOMMITTEE ON METEOROLOGICAL PROBLEMS

The Subcommittee on Meteorological Problems keeps in contact with the progress of investigations being conducted by the various agencies on problems relating to atmospheric conditions which are of particular importance in connection with aircraft design and operation. The Special Committee on Lightning Hazards to Aircraft is organized under the Subcommittee on Meteorological Problems.

Atmospheric disturbances and their effect on airplane operation.—The Langley Memorial Aeronautical Laboratory has continued its study of gust intensities and gradients and their effect on airplane accelerations in flight. Additional records have been obtained on both military and commercial airplanes by means of N. A. C. A. V-G recorders, the total number of hours of flying time accumulated on commercial transports having been increased to 82,000. One incident of particular interest was reported in which a military airplane was subjected, without previous warning to the pilot, to an isolated strong gust of an intensity usually associated with that of severe thunderstorm conditions. In this gust the effective gust velocity was more than 30 feet per second.

The accumulation of data by means of V-G recorders has included operation over the principal air lines in the United States, on the routes from the East Coast to Bermuda and to the northern part of South America, over the Andes Mountains, and across the Pacific and the Atlantic.

From statistical data obtained on a number of airplanes it appears that the gust gradient distance is directly proportional to the size of the airplane and is approximately 8.5 times the wing chord length. By means of flights in thermal gusts to altitudes up to 17,000 feet, a correlation has been obtained between the gust velocity and various other factors, including the gradient distance, wind velocity, wind gradient, thermal energy, and altitude.

Lightning hazards to aircraft.—Data are being accumulated from air transport operators by means of a questionnaire on incidents of lightning strikes to airplanes, and an analysis of the information so far obtained has been made. It is of interest that, although there have been a number of instances of lightning strikes to airplanes, the resulting damage to the aircraft was slight, and in a large number of cases the passengers, and occasionally even the pilots, were not aware of the incident.

A study is being made at the University of New Mexico, under the cognizance of the Special Subcommittee on Lightning Hazards to Aircraft of the location and intensity of electrical charges in the atmosphere. Evidence obtained in this investigation indicates that discharges from cloud to ground are of a negative polarity. Investigations are being conducted in electrical research laboratories on the effect of electric discharges simulating lightning strikes on sheet metal of various types, particularly those used in aircraft construction. From information so far obtained it appears that it is possible to determine from the size of a hole caused by lightning in any given thickness of metal the amount of current involved. It is planned to accumulate from aircraft operators samples of burned metal removed from airplanes on which lightning strikes had been experienced and determine the amount of the current which caused the burn.

Careful consideration has been given to the specific hazards from lightning to various portions of the airplane such as radio equipment, gasoline tanks, fabric covering, control mechanisms, etc. It is believed that, if suitable precautions are taken in all cases, the danger from lightning to an airplane in flight is slight. The avoidance in all cases of atmospheric conditions which indicate the probability of lightning is considered desirable, however, and instructions to this effect have been issued by one airline operator to its flying personnel, with material reduction in the number of lightning strikes experienced.

#### SUBCOMMITTEE ON SEAPLANES

The relative importance assigned to the various hydrodynamic problems connected with the design and construction of seaplanes, which are under the cognizance of the Subcommittee on Seaplanes, has changed radically during the past year. For several years the major hydrodynamic problem has been that of resistance, and the possibility of successfully getting into the air was considered to be largely determined by that factor. Today the major hydrodynamic problems appear to be (1) dynamic stability while in motion on the water, (2) spray, and (3) seaworthiness. This almost sudden change has come about because of the pressure on the designers of demands for extreme performance in the way of speed, range, and pay load. In the endeavor to produce hulls having minimum air drag and structural weight, the almost universal tendency has been to adopt forms having relatively narrow and deep cross sections.

This form also gives the familiar arrangement of the passenger accommodation in civil craft. But narrow hulls have meant heavily loaded hulls; the high position of wings and engines—and, in many cases, fuel—has caused the center of gravity of the whole

craft to rise to surprisingly high positions; the heavily loaded wings and high air speeds have caused landing speeds to be considerably increased. As a result of these changes, the difficulties associated with obtaining adequate longitudinal stability (freedom from "porpoising"), freedom from excessive spray and from spray thrown into the propellers, and moderate impacts of the bottom on the water while landing and taking off have been greatly increased. At the same time, the use of engines with greatly increased horsepower available for take-off, because of the increased power needed for flight at higher speeds, and the general use of automatic or controllable propellers with greater efficiencies in the range of take-off speeds, have made the water resistance of the hull of much less importance in determining whether a seaplane can get into the air. This situation has made it necessary to broaden the scope of the Committee's work and to undertake the provision of additional facilities to enable adequate consideration of the new problems.

Apparatus and technique to conduct the investigations made necessary by the new problems have been developed and expanded as rapidly as possible. Equipment of a semipermanent type has been constructed, and appropriate methods of operation have been developed for testing dynamically similar models of complete flying boats for the purpose of studying their dynamic stability. Methods of constructing the very special type of models required for this work have been devised. Accurate methods of ballasting the models so that the weight and the moment of inertia about the center of gravity will correspond to those of the full-size craft have been developed. The theory on which a mathematical study and a determination of the stability may be based has been investigated and a revised treatment, based on that of Perring and Glauert, has been begun. A sound theoretical treatment will be very helpful in the understanding of this very complex problem and in the direction of the broad fundamental research that must be carried out if the problem is to be solved.

With the limited equipment already at hand, it has been possible to investigate the dynamic stability of two specific machines for the Bureau of Aeronautics and of one for a private corporation.

Work for the military services of the Government has continued to receive first priority in the work of the tank. Four investigations of specific flying-boat projects and two investigations of novel devices have been completed. Several projects requiring the high towing speeds available only at the N. A. C. A. tank were completed for the Navy.

The fundamental researches completed and under way were of interest because of the use in several cases

of large families of related models to study the influences of form on the hydrodynamic qualities and because the scope of the investigations was extended to include aerodynamic effects as obtained in parallel wind-tunnel tests on the same models.

**Plant and equipment.**—The efficiency of routine tests in smooth water has been increased by the installation in the tank of devices that damp out the surges caused by the operation of the carriage and by the perfecting of more durable wave suppressors. The development of these devices, as well as the design of a wave-making device, has been facilitated by the construction of a small tank one-eighth the cross section of the N. A. C. A. tank and 50 feet long. This tank has large glass panels in the sides and in it large models of the devices can be operated while the motions of the water about the models are observed.

**Hulls for long-range flying boats.**—In a long-range aircraft, small increases in air drag have a large influence on pay load and the best form of hull for such a craft presumably is one that approximates a streamline body and departs from such a form only by the amount required to give satisfactory hydrodynamic qualities. It is anticipated that the trend of design will be toward such forms, and both tank and wind-tunnel data are being accumulated to aid in their further development.

Technical Note No. 668 describes tests in the tank and in the 20-foot wind tunnel of two models of the planing type of hull, the forms of which are derived from a body of revolution and which represent extreme aerodynamic refinement as compared with existing hulls. The tank tests showed that the models were generally satisfactory but under certain conditions developed a tendency to behave unsatisfactorily. Take-off calculations for an assumed giant flying boat indicated that its take-off characteristics would be satisfactory if the trim was properly controlled. These models had lower air drag for the same volume than any models previously tested in the 20-foot wind tunnel. They also possessed the desirable characteristic of having smaller than usual increases in drag with departures from the angle for minimum drag.

It was apparent from the tank tests that there is in general no sharp line between good and poor water performance to determine the practical limits of aerodynamic refinement. A family of models has therefore been devised having systematic variations in the degree of departure from a streamline body. Tests of this family, now in progress, will provide further information on the best compromise between desirable aerodynamic and hydrodynamic qualities.

**Outboard floats.**—The best form of outboard float also represents a compromise between the requirements of low aerodynamic drag and satisfactory characteristics



on the water. As part of a program for the investigation of outboard floats, four models of typical floats were tested in the tank and in the 20-foot wind tunnel (Technical Note No. 678). From the data obtained, the forms were compared on the basis of aerodynamic drag, spray, and yawing moments for given righting moments. Others factors, such as relative angle of heel, possible impact loads, and structural simplicity, were also considered in the analysis. It was concluded that the best form for an outboard float, when all its requirements are considered, is one having a transverse step for good planing characteristics and having its buoyancy distributed horizontally rather than vertically.

**Tests of models of representative flying-boat hulls.**—A one-sixth-size model of the hull of a Navy flying boat was investigated in the tank as part of the general program of tests of typical hull forms. This hull was a more recent adaptation of the NC type and was of special interest because of several features intended to improve take-off performance. These features included pronounced chine flare on both forebody and afterbody, a downward hook in the surface of the bottom at the step, and a tail extension shaped to provide additional hydrodynamic lift at low speeds. The hydrodynamic characteristics were found to be very satisfactory over a wide range of loadings and speeds. The results of the general test have been published in Technical Note No. 681.

In this publication a new type of chart was introduced for use in calculations of take-off performance based on the data from the general test. Since at a given speed, load and resistance are functions of the trim, the data are plotted in the form of resistance coefficient against trim with load coefficient as parameter. A number of such plots are made for a succession of speed coefficients such as would be used in a step-by-step calculation of take-off events. The curves of trimming-moment coefficient are superposed on these plots in the form of contours of constant trimming-moment coefficient. Experience with these charts has shown that they are preferable to the previous charts plotted against speed coefficient because of the greater ease of interpolation and the wider application to problems involving arbitrary conditions of trim or trimming moment.

#### SPECIAL SUBCOMMITTEE ON VIBRATION AND FLUTTER

The problems of flutter and vibration, especially in the case of large fast airplanes, continue to be increasingly important. During the past year, two meetings of the Special Subcommittee on Vibration and Flutter and a special conference on these problems were held. At one of the meetings, the problem of flutter was discussed with representatives of the industry. The calculation of the flutter speed and the parameters

necessary for its determination were considered, particularly with a view to the possible means of reducing the labor involved in making such calculations.

A special conference with manufacturers was held at Langley Field and considered the difficulties being experienced with propeller vibration. At this meeting, equipment for the study of the fundamentals of propeller vibration and damping was discussed. This equipment has now been completed and is ready for operation.

Most of the work on vibration carried out this year by the Committee has been related to the problem of flutter. In addition to the theoretical and experimental work on flutter, several projects on vibration have been undertaken because of their importance in relation to the problem of flutter.

**Ground tests.**—Vibration tests have been made on a number of airplanes on the ground. Equipment and methods have been developed to facilitate these measurements.

**Damping tests.**—The problem of determining values of structural damping for use in flutter calculations has been studied. Methods have been developed for separating the motions associated with different normal modes.

**Model beams.**—Exact solutions have been obtained for the equation of torsional vibration of a very general class of tapered beams (Technical Note No. 697). Tests on a set of tapered beams have been made and compared with theoretical results for both torsion and bending. These results indicate the effect of taper upon frequency for most cases of tapered wings.

**Elastic airplane model.**—A model of convenient size having elastic properties and weights distributed similarly to those of a typical modern airplane has been built. This model has been used in tests conducted to develop a technique of determining the various elastic, mass, and coupling parameters determining the flutter properties of the wing and the tail.

**Flutter problem.**—Flutter calculations have been continued during the past year. Particular attention has been given to the calculations for three degrees of freedom in order to determine more carefully when these can be replaced by the simpler cases for two degrees of freedom. The flutter parameters of several present-day airplane wings have been determined. A number of aircraft companies have cooperated by supplying information concerning the structural parameters.

The theoretical work on flutter has been extended to include the effect of aileron tabs and servorudders.

Further contributions to the flutter problem have been made through the study of unsteady-lift functions for wings of finite aspect ratio (Technical Note No.

682) and the experimental verification of the theory of oscillating airfoils (Technical Report No. 673).

## REPORT OF COMMITTEE ON POWER PLANTS FOR AIRCRAFT

### LANGLEY MEMORIAL AERONAUTICAL LABORATORY

#### INCREASE IN ENGINE POWER

The prime requisites for aircraft power plants at the present time, either for military or commercial service, are increased power for take-off and altitude operation, as well as greater economy in fuel consumption. Additional power is being striven for, principally through the development of fuels with higher antiknock values and increasing the effectiveness and number of the power strokes. The importance of the fuel work is indicated by the fact that improved fuels have contributed to a large extent in doubling engine power during the past decade. Further improvements in supercharging can be expected to provide materially higher intake manifold pressures and therefore greater power at altitude. Engine operating speeds are also being raised. The power requirements of the larger aircraft, exceeding as they do the capabilities of existing engine types, has led to the development of engines with more cylinders and consequently greater displacement. The thermal and mechanical limitations to achieving increased power centers principally on the cooling of the exposed parts in the combustion chamber and on carrying the loads imposed on the principal bearings. Fuel economy is now of the utmost importance, both because of its effect on the range of military equipment and on the operating expense of commercial aircraft. The greatest improvements in economy are anticipated from the reduction of power-plant and cooling-system drag and the recovery of waste heat. Renewed interest is being taken in in-line liquid-cooled power plants because of their small frontal area, while intensive work is going forward to provide minimum-drag cowlings for the radial air-cooled engine types and more efficient means of dissipating the heat in both air- and water-cooling systems. Savings of as much as 15 to 20 percent of the total airplane drag are possible by these means. The problem of waste heat recovery is particularly important, since only some 30 percent of the heat value of the fuel is utilized in the present-day power plants. The Committee is actively engaged in researches designed to provide practical solutions for many of these problems, as will be seen from the following report.

**High octane number fuels.**—In the development of aircraft engines it is becoming increasingly important that the engine designer know the effect of the different engine operating conditions on the maximum

permissible engine performance. For this reason the Committee is conducting an investigation to determine the relationship between maximum permissible engine performance and the knocking characteristics of aircraft-engine fuels. This investigation is under the cognizance of the Subcommittee on Aircraft Fuels and Lubricants and is described in the report of that subcommittee.

**Flow through engine inlet valves.**—The results of the investigation of flow coefficients with intermittent flow through engine poppet valves have been published in Technical Note No. 701.

A sleeve valve and cylinder have been assembled for determining the flow coefficients of the inlet ports with pressure drops through the valve at values up to 8 pounds per square inch. Over-all flow coefficients have been measured with the valve operating as in an engine. Coefficients with the sleeve valve partly opened have been measured with the sleeve stationary, and the coefficients that apply to these partial openings have been checked against the over-all flow coefficients. A preliminary comparison shows the flow coefficients of sleeve valves to be the same for the partly opened valve as for the fully opened and operating valve. The coefficients derived from the test data are about the same as those obtained previously for the poppet valves.

**Piston temperatures.**—The investigation of the important factors controlling piston cooling and the effect of engine and cooling conditions on piston temperatures has been continued. The temperatures at five locations on a piston of an air-cooled engine have been determined for varying engine speed, load, spark advance, fuel-air ratio, head and barrel temperature, and oil temperature and viscosity. The data are being analyzed and will be prepared for publication.

**Piston rings.**—Piston-ring sticking, loss of tension, and wear are failures that limit the output of high-performance engines. An investigation is in progress to determine the engine-operating characteristics of superior cast-iron and nitrided-steel piston rings when operated in nitrided-steel liners. The use of piston rings of those materials and compounded lubricating oils have greatly reduced ring sticking and loss of tension. The problem of reducing the wear of piston rings in high-output engines is being studied.

**Valve-overlap investigations.**—The use of large valve overlap and increased inlet manifold pressure is an efficient method of removing the residual exhaust gases from an engine cylinder and of cooling the surfaces of the combustion chamber. The work on the single-cylinder test engine has been extended to a nine-cylinder radial spark-ignition engine equipped with an injection system spraying the fuel into the

cylinders. The engine was fitted with a special cam giving approximately 130° overlap between the open periods of the exhaust and the inlet valves. The poor idling of the engine experienced with large amounts of valve overlap was overcome by placing separate throttle valves close to the intake port of each cylinder. With these auxiliary throttles, the idling with large valve overlap was equal to the idling with the standard throttle and standard engine timing.

**The 2-stroke-cycle engine.**—Research has continued on the factors affecting the performance of the 2-stroke-cycle fuel-injection spark-ignition engine. The liquid-cooled engine used in this investigation is a uniflow type having scavenging and charging air admitted to the cylinder through piston-controlled inlet ports and exhaust through four poppet valves in the head. The factors investigated have included the number, the size, and the angle of the inlet ports and the lift and the timing of the exhaust valves. Investigations are in progress to increase performance by more effective breathing capacity and increased engine speed.

**Recovery of energy in exhaust gases.**—The conventional aircraft engines discharge as waste heat 65 percent of the energy of the fuel. Since the weight of fuel constitutes about half of the useful load of a long-range airplane, it is extremely important that methods be developed for utilizing a part of this waste energy. An analysis has been made of the energy recoverable by methods that require no additional prime movers but depend on the forward motion of the airplane. The pressure variation attending the flow of cooling air through the duct of the cooling system provides a convenient thermodynamic cycle for recovering waste heat. Thrust is obtained from the increased velocity of the cooling air as it leaves the duct exit.

The power recoverable by this method has been calculated for three conditions: first, for the normal duct radiator; second, for the duct radiator having the heat in the exhaust gas transferred to the cooling air in the duct; and third, for the duct radiator having the exhaust gas discharge into the duct. The effect of a fan in the duct for increasing the compression ratio of the thermodynamic cycle has been considered. A report is in preparation covering the results of this investigation.

**Jet reaction as take-off aid.**—The possibility of using auxiliary jet propulsion for aid during the take-off has been analyzed and compared with the use of larger engines. The analysis shows that the weight of fuel and liquid oxidant required for an appreciable improvement in take-off performance is sufficiently small to indicate that serious consideration should be given to this method of assisting the take-off when take-off aid becomes necessary. A report based on this analysis is being prepared for publication.

#### COMBUSTION RESEARCH

**Knock investigation.**—The construction of the N. A. C. A. high-speed motion-picture camera was completed during the past year. With this camera motion pictures can be taken at rates up to 40,000 photographs per second, whereas previous pictures had been taken at speeds of 2,400 pictures per second. Projecting these motion pictures at speeds of 16 photographs per second gives the effect of increasing the visual speed of the observer 2,500 times.

The motion pictures of combustion obtained with the new camera and the N. A. C. A. combustion apparatus have made possible a detailed study of the combustion process. Throughout this investigation, schlieren photographs have been taken because past experience has shown them to be superior to the usual flame photographs. When knock occurs in the engine, the photographs show that the phenomenon is completed in from 0.00005 to 0.00010 second. The photographs emphasize the fact that knock appears to be a much different phenomenon from the normal combustion which precedes the knock. The actinic value of the knocking flame is many times that of the flame previous to knock. With severe knock, a preknock reaction in the end gas, which has been previously observed, is clearly shown.

The results of the investigation made to determine the effect on air movement within the engine cylinder of several arrangements of shrouded intake valves have been published in Technical Report No. 653.

An investigation of the effect of air flow within the combustion chamber for spark-ignition engines on the propagation of combustion has been reported in Technical Report No. 657.

**Preignition characteristics of fuels.**—The N. A. C. A. combustion apparatus has been used to investigate the preignition characteristics of aircraft-engine fuels. For the purpose of these tests preignition of the fuel was caused by an electrically heated coil located in the combustion chamber. The temperature of the coil was measured by a thermocouple. Fuels included in the investigation were iso-octane, benzene, toluene, methyl alcohol, and different fuel blends. In general, the results have shown that the preignition temperature is not greatly affected by engine speed or compression ratio. The preignition temperature remains fairly constant as the fuel-air ratio is decreased from a rich mixture until the mixture approaches that for complete combustion of both fuel and air. Any further leaning causes a sharp increase in the preignition temperature. The results have shown that there is no general relation between the knocking characteristics and the preignition characteristics of a variety of fuels. The results of this investigation are being prepared for publication.

**Engine charge temperature.**—An investigation has been undertaken of the heat-transfer process during the intake and compression strokes of an internal-combustion engine in order to facilitate a study of knock in aircraft engines. Indicator diagrams have been obtained on a Wright 1820-G single-cylinder test engine, from which the engine charge temperature at the end of the induction and compression strokes has been computed. The variation of charge temperature with engine speed, throttle setting, air-fuel ratio, inlet-air temperature, and cylinder-wall temperature has been determined.

**Air flow in engine cylinders.**—For fuel injection into the cylinders of an aircraft engine, it is necessary that an air swirl be produced in the cylinder or that a high degree of air turbulence exist to assist in distributing the fuel spray. The investigations to determine the effect of inlet-port and valve design on the air movement within the cylinder of an internal-combustion engine have been continued. Two cylinder heads simulating air-cooled engine practice were constructed and tested on the glass-cylinder engine. In both cases the air movement was partly controlled by the design of the intake port in the cylinder head. With one arrangement the air rotated about the cylinder axis and with the other a vertical swirl was produced. Both designs were effective in giving good engine performance. The results are being prepared for publication.

#### FUEL CONSUMPTION

**Fuel distribution.**—The results of the investigations made to obtain a comparison of the performance of an engine with a carburetor, with fuel injection into the inlet manifold, and with fuel injection into the cylinder have been published in Technical Note No. 688.

**Increase in compression ratio.**—Modern aircraft engines operate at compression ratios of from 6.0 to 7.5. An appreciable reduction in fuel consumption may be obtained by operating at higher compression ratios. An investigation is in progress on a single-cylinder engine to determine the improvement in power output and fuel consumption to be obtained with an air-cooled cylinder having a displacement of 200 cubic inches when operated over a range of compression ratios from 7.4 to 10.2. The fuel is injected into the engine cylinder. At a compression ratio of 9.2 and with atmospheric intake pressure, a brake mean effective pressure of 182 pounds per square inch was obtained at 1,750 r. p. m. The corresponding brake fuel consumption was 0.356 pound per brake horsepower-hour.

**Fuel economy in flight.**—Military operation often requires flight speeds at or near the maximum. As the maximum power condition of an airplane engine is approached, sacrifices in fuel economy must be made to avoid overheating and detonation. It is important that

the fuel consumption be kept as low as possible consistent with safe operation, since the fuel load is a large part of the disposable load of the airplane. An analysis has been made of the methods of increasing power for maximum fuel economy, with detonation and cylinder temperatures as limiting conditions. The results of the analysis showed that the least hourly fuel consumption is obtained at the lowest practicable engine speed and with an approximately correct mixture. Starting from these conditions the methods of increasing power in the order of fuel economy were shown to be:

(a) Increasing manifold pressure at constant minimum practicable engine speed to the point of incipient knock or to full throttle if knock is not encountered.

(b) Increasing engine speed and maintaining constant cylinder temperatures by cooling within knock limits until maximum engine speed is reached.

(c) Retarding the spark or reducing the cylinder temperatures to permit higher manifold pressures.

(d) Increasing the fuel-air ratio to permit higher manifold pressures.

A report has been prepared covering this material.

**Safety fuels.**—Renewed interest has been shown in the use of new safety fuels having the same heating value as gasoline and relatively good antidetonating qualities. The flash point of these fuels is about 115° F., which should result in an appreciable reduction in the fire hazard when used in aircraft. The preliminary tests made with one of these safety fuels having a distillation range from 325° to 425° F. showed that in a single-cylinder engine fitted with a modern air-cooled cylinder the power and fuel consumption are equal to that obtained with gasoline having the same antidetonating qualities.

#### ENGINE COOLING

**Cooling of finned cylinders.**—A report has been published (Technical Report No. 674) covering an investigation of the cooling on the front of an air-cooled engine cylinder. The results show the relative effect of various operating conditions and fin dimensions on the cooling of a finned cylinder in a conventional cowl. An analysis of the cooling problem on an air-cooled engine has been made to show what may be done to improve the cooling and what each improvement requires in increased power expended for cooling. Cooling at altitude was also studied, as well as the relationships between indicated horsepower, cooling requirements, and cooling on the ground.

**Fin dimensions.**—The analysis to determine the proportions of aluminum, copper, magnesium, and steel fins necessary to dissipate maximum quantities of heat for various fin widths, fin weights, and air-flow conditions has been completed. The analysis includes the

determination of the optimum fin proportions when specified limits are placed on the fin dimensions. In addition to the information presented on the design of fins, this investigation shows that optimum fin dimensions are not appreciably affected by the differences in air speed obtained with different air-flow arrangements or by small changes in the length of the air-flow path. For a given fin weight, the highest heat transfer can be obtained with fins of a magnesium alloy; pure copper and aluminum-alloy fins are only slightly inferior to magnesium-alloy fins and will dissipate several times more heat than steel fins. The results of this investigation have been prepared for publication.

**Heat-transfer coefficients.**—The investigation to determine the surface heat-transfer coefficients of finned cylinders has been completed and the results have been published in Technical Report No. 676. The investigation covered the determination of the effect of fin width, fin space, fin thickness, and cylinder diameter on the heat transfer. Wind-tunnel tests were made in a free air stream with and without baffles and also with various devices for creating a turbulent air stream. Tests were also made with blower cooling. Correlation of the surface heat-transfer coefficients measured on 58 finned cylinders was found possible by plotting factors including the air-stream characteristics and the dimensions of the finned cylinders.

**Heat-transfer process.**—A report has been prepared covering the heat-transfer process in a Wright Cyclone engine. Equations for the cylinder head and barrel temperatures as functions of the important engine and cooling conditions are given. A method of correlating and comparing cooling data is presented and is illustrated by curves obtained from data on multicylinder engines in flight and on the test stand, and from single-cylinder test data. The distribution of temperature around the cylinder head and barrel and the correlation of temperatures at individual points on the cylinder are discussed. Calculated curves are presented showing the variation of cylinder temperature with altitude in climb and level flight. Data are also presented showing the variation of cylinder head and barrel temperatures with time when the throttle is suddenly opened and when the cooling air speed is suddenly decreased.

**Heat-transfer coefficients in flight.**—Apparatus has been installed in an airplane and several tests made to determine the surface heat-transfer coefficients of an electrically heated finned cylinder in flight. The object of these tests is to determine heat-transfer coefficients in flight and compare them with those obtained in the laboratory.

**Single-stage axial-flow fan.**—Calculations have been made for a single-stage axial-flow blower to determine its suitability for cooling airplane engines. Pressures

in the neighborhood of 10 inches of water appear to be attainable with efficiencies of more than 80 percent. A fan of this type seems to be suitable for large present-day engines. Although some installation problems have been encountered, they do not seem to be insurmountable, especially for the large radial engines having more than one row of cylinders.

**The N. A. C. A. air-cooled cylinder.**—The method developed by the Committee for bonding preformed aluminum-alloy fins to the cast aluminum-alloy air-cooled cylinder heads has permitted a large increase in the power output that can be obtained from a cylinder having a given displacement. Two air-cooled cylinders have been constructed having the fins attached by this method and the performance of the cylinder has been determined on a single-cylinder engine. The cylinders have the same internal dimensions as a conventional air-cooled engine cylinder but five times the fin surface. For the same power output and same cylinder temperatures, the amount of air required for cooling the N. A. C. A. cylinder is only 35 percent of that required to cool the conventional cylinder. For the same pressure drop across the cylinders, 15 inches of water, and the same cylinder temperatures, it is possible to obtain nearly three times the power from the N. A. C. A. cylinder as from the conventional cylinder.

Preliminary tests showed that satisfactory cooling could be obtained on the N. A. C. A. cylinder with a pressure drop across the cylinder of only 2 inches of water when operating at an engine speed of 2,100 r. p. m. and a boost pressure of 5 pounds per square inch.

#### SUPERCHARGER RESEARCH

**Performance of superchargers.**—The computations on the performance of superchargers having a range of compression exponents from 1 to 2 and operating at altitudes from 0 to 80,000 feet over a wide range of boost pressures are being analyzed. The application of these results to the engine shows that if a geared centrifugal supercharger is used to maintain sea-level pressure to an altitude of 50,000 feet the fuel consumption will be twice that at sea level. This increase is due to the large amount of power required by a gear-driven supercharger. With the turbosupercharger there is no large increase in fuel consumption because the energy to drive the supercharger is taken from the exhaust gases. This analysis will be continued to include the application to engines of high compression ratios.

**Air intercoolers.**—The problem of increasing the anti-knock value of fuels by air intercoolers includes the important consideration of the power necessary to force both cooling air and engine-charge air through the intercooler and also the power required to carry the weight added by the intercooler. A theoretical and experimental investigation is being made of a light-

weight type of intercooler that is expected to reduce charge temperatures materially with relatively low-pressure drop across the intercooler. A test unit of this intercooler is being constructed for laboratory testing.

Programs of investigation have been completed on radiator design and installation and on intercooler design for aircraft. Tests are being continued on tube banks in order to obtain more information on the detached mechanism of heat transfer and friction loss.

**Engine power at altitude.**—The calculation of flight performance at altitude is dependent upon the accurate determination of the variation in engine power with altitude. Several different formulas are available in the literature for correcting engine power at sea level to altitude conditions. A comparison has been made between the calculated engine power and the power as measured on an air-cooled engine in flight by use of the N. A. C. A. torque meter. The range of altitudes covered was from sea level to 20,000 feet. The engine power as measured by the torque meter checked the power as corrected for temperature and pressure by the use of well-established formulas. The results of this investigation and of a study of the variation of engine power with altitude are being prepared for publication.

#### COMPRESSION-IGNITION ENGINES

**Combustion research.**—The performance of high-speed Diesel engines is less than that of the conventional Otto-cycle engine because of the inability of the Diesel engine to burn efficiently the total air charge inducted into the cylinder. As a result, the Diesel engine requires a higher boost to obtain the same take-off mean effective pressure than does the spark-ignition engine. Apparatus has been assembled that will permit an extensive survey to be made of the mixture during combustion in a Diesel engine. Heretofore, such an investigation has been of doubtful value because it required several engine cycles to obtain a large enough sample of the mixture to analyze. The development of an industrial microanalyzer capable of analyzing volumes as small as  $\frac{1}{20}$  milliliter has made it possible to collect an adequate sample from a single cycle. For this purpose a hydraulically operated gas-sampling valve has been developed that, during an opening period of 0.0004 second, will collect a sufficiently large sample from a predetermined section of the combustion apparatus.

A report has been prepared and published as Technical Note No. 707 presenting results of engine performance tests of fuel oils, mixtures of fuel oil and alcohol, and fuel-oil dopes.

The results of the investigation of ignition lag of Diesel oils as determined in a bomb and in an engine have been published in Technical Note No. 710.

**Fuel-injection systems.**—Previous investigations with a simulated unit injection system have demonstrated certain advantages for this type of injection system over the more conventional type in which a length of tubing connects the injection pump to the injection valve. For this reason, a unit injector has been tested to determine the effects of the various operating variables on the rates of fuel discharge. It has been found that, when an outwardly opening injection nozzle is used, the rates of fuel injection closely follow the rate of fuel displacement by the pump plunger. Under very high injection pressures, however, the compression of the fuel in the injection system causes the rate of discharge to be less than the rate of plunger displacement. Secondary discharges are eliminated when a unit injector is used and higher rates of discharge are obtained than are practicable with the injection pump mounted at some distance from the injection valve. The results of this investigation are being prepared for publication.

**The 4-stroke-cycle engine.**—The N. A. C. A. displacer-type combustion chamber has been adapted to an air-cooled cylinder having a 5-inch bore and a  $5\frac{1}{2}$ -inch stroke. From the results of single-cylinder engine performance tests, multicylinder engine performance has been computed. On the basis of the weights of the single-cylinder parts, the weight of a nine-cylinder radial engine has been computed. These computed values indicate a specific weight of 1.6 pounds per horsepower for an output of 500 horsepower. From the results of single-cylinder tests, heat loss, heat-loss distribution, and cooling measurements have been calculated. An investigation has been started to determine the air-charging restrictions peculiar to the displacer-piston type of combustion chamber.

**The 2-stroke-cycle engine.**—The liquid-cooled engine used in this investigation has piston-controlled inlet ports directed at  $56^\circ$  to the radial and exhausts through four poppet valves in the head. Engine-performance tests have been made with various rates of injection and various fuel-spray orifices in two diametrically opposed fuel valves, each valve injecting downstream with the rotating air flow. Tests have been made with reduced inlet and exhaust time areas to determine the amount of power reduction and exhaust characteristics. Preparations have been made to improve the air charging by using four rows of inlet ports and to increase power by increasing the engine speed to 2,400 revolutions per minute.

**The 2-stroke-cycle sleeve-valve engine.**—Analysis has shown that the single sleeve-valve mechanism should give better breathing capacity and higher allowable rotative speeds than the Committee's poppet-valve engine. With the object of determining engine-performance characteristics, a design has been completed



of a single sleeve-valve engine. The necessary parts for the test engine are now under construction by the contractor.

#### NATIONAL BUREAU OF STANDARDS

**Phenomena of combustion.**—A large number of photographs of explosions in a 10-inch spherical bomb were taken through a narrow window which formed a part of the bomb wall. In addition to the flame trace, each record contained a time scale in thousandths of a second and six points on the time-pressure curve. Mixtures of the fuels benzene, normal heptane (zero octane number), and iso-octane (100 octane number) with oxygen and nitrogen were studied. A technical report giving the detailed experimental results and the conclusions which have been drawn for the three hydrocarbons as well as those for previous measurements with carbon monoxide is being prepared for publication.

In all the explosions there is a general increase in the transformation velocity as the temperature and pressure of the unburned charge rise because of the adiabatic compression. Since the range of initial conditions was wider for carbon monoxide, it was possible to analyze these results for the independent effects of temperature and pressure, and both were found to contribute to the increase in transformation velocity. For the hydrocarbons in comparable mixtures, the transformation velocity is highest for benzene and lowest for iso-octane, with heptane intermediate. The addition of tetraethyl lead to the heptane mixture produced no appreciable change in flame speed. Thus, under the conditions of the experiments there appears to be no relation between transformation velocity and the tendency to knock.

Until the late stages of the explosion there is no measurable difference among the hydrocarbon fuels in the pressure rise produced when a given fraction of the charge is inflamed. For all the explosions the rise in pressure for a given mass of charge inflamed is considerably less than would be expected from calculations based on thermal data and the assumption that reaction goes to equilibrium in a very thin flame front. The results therefore indicate that the liberation of energy continues for some time after the flame front has passed. Observations of the gas movements within the sphere of flame, made by following the bright trails left by burning particles of gunpowder suspended in the mixture, also indicate the existence of continued reaction within the inflamed gases.

Since no connection could be found between any of the characteristics of the normal burning of the hydrocarbon fuels and their relative tendency to knock in an engine, a supplementary study of the influence of various factors upon the transition from normal burning to detonation has been undertaken. Construction of ap-

paratus for this purpose was begun, while preparations for a series of measurements in the spherical bomb on triptane (2, 2, 3-trimethylbutane) were being completed.

**Flow characteristics of fuel lines.**—In connection with a cooperative attack on aviation vapor-lock problems, the Bureau has investigated the resistance to fuel flow in fittings and accessories of  $\frac{1}{2}$ -inch tubing and in  $\frac{5}{8}$ -inch tubing as a function of rate of flow and relative amounts of liquid and vapor flowing. The resistance of any fuel-system component to liquid flow is approximately doubled when equal volumes of liquid and vapor are present. It has been demonstrated that the resistance of conventional elbows can be reduced materially by redesign of the fitting, and a simple type of pressure tap has been developed which is suitable for general use, particularly in fuel system mock-ups.

**Engine testing.**—A study of the characteristics of oils and their effect on engine condition was made at the request of the Matériel Division of the Army Air Corps. The tests consisted of a series of 50-hour endurance runs on a 9-cylinder air-cooled engine mounted on a rigid stand.

Altitude tests were made on an aircraft auxiliary power plant for the Bureau of Aeronautics, Navy Department. Altitude tests on stationary power plants for beacon lighting, teletype, and other airway equipment were made at the request of the Civil Aeronautics Authority.

**Temperature surveys.**—Ground and flight temperature surveys have been continued on all new types of Navy aircraft engines. These include cylinder, oil, and intake-mixture temperatures.

**Spark plugs.**—A method of bench testing mica spark plugs has been put into service use with satisfactory results. Further investigation into materials and designs of spark plugs to meet the more exacting requirements of commercial and military services is under way.

**Aircraft-engine cylinder wear.**—An investigation was made to determine the cause of cylinder wear, particularly on the rear wall. From the data obtained for two continuous 50-hour runs on an air-cooled single cylinder engine, it was found that wear on the rear wall was caused chiefly by corrosion. Factors in the acceleration of the corrosion were the antiknock compound used, the lubricant, and the temperature distribution of the cylinder.

#### SUBCOMMITTEE ON AIRCRAFT FUELS AND LUBRICANTS

**Investigation of antiknock characteristics of fuels.**—The investigation of the relationship of engine operating conditions to the antiknock characteristics of fuels has been continued. From the results obtained with a flat-disk combustion chamber and a pent-roof combustion

chamber an analysis has been made in which the maximum permissible engine performance under a variety of engine operating conditions has been derived from an experimental determination of the maximum permissible performance under a few conditions. The analysis shows that, from considerations of knock, the most important independent variables in any one engine are the inlet-mixture density and temperature and the mixture ratio. The data show that preignition must be treated separately from knock if fuels are to be adequately rated in an engine.

The analysis shows that, for any particular fuel, the maximum permissible power increases as the compression ratio is decreased, provided that the inlet air temperature is maintained constant and the performance is limited by knock and not by preignition. For cases in which the inlet air is heated an increasing amount as the boost pressure is increased, an optimum compression ratio exists for the engine from the consideration of maximum permissible power. The data show that a certain amount of correlation is possible between the curves of knock characteristics of several fuels from tests on different engines, but that certain differences are caused by engine design. The results of this investigation have been published in Technical Report No. 655.

A portion of the investigation has been completed on the determination of the knock characteristics of a cylinder with a semispherical combustion chamber. Although in general the results are the same as those obtained from the flat-disk and pent-roof combustion chambers, certain differences in the correlation of the data result from the difference in cooling characteristics of this engine. This investigation is being continued.

Additional tests of fuels are being conducted on a high-speed C. F. R. engine. With several fuels of 100 octane number used in this engine, different values of highest useful compression ratio were obtained as the inlet-air temperature was varied. The results also indicate that the effect of engine speed on maximum permissible performance may be a temperature effect resulting from the transfer of heat from and to the incoming mixture rather than being a time effect as has been previously suggested.

Investigation to develop nonleaded aircraft fuel of over 100 octane number.—This investigation, carried on by the National Bureau of Standards for the past two years in cooperation with the National Advisory Committee for Aeronautics, the Army Air Corps, and the Bureau of Aeronautics of the Navy Department, has been in a confidential status until recently. The program calls for the preparation of branched-chain paraffin hydrocarbons in the volatility range of aviation

gasoline, and the investigation of their knocking tendencies and their physical properties.

Two automatically controlled fractionating columns were designed and installed for this work. Both columns have efficiencies of at least 100 theoretical plates and operate, practically without attention, day and night, Sundays and holidays, barring an unexpected failure of the electric power supply. These columns serve to separate and purify synthetic products and to isolate materials from industrial crudes. The project has required the construction of Grignard reactors, hydrogenators, and other necessary equipment for organic synthesis.

One of the first hydrocarbons prepared in this laboratory was 2,2,3-trimethylbutane, also called triptane, preparation of which was begun June 1, 1938. As the fractionating columns had not been completed at the time, this material was not finally purified until early in 1939, shortly after an industrial laboratory had reported that triptane was well over 100 octane number. When the Bureau's final product was blended with an equal volume of 90 octane reference fuel (90 percent iso-octane and 10 percent heptane) the octane number of the blend was over 99, indicating pure 2,2,3-trimethylbutane to be about 108 ASTM octane number. Six liters of this compound were supplied to the Langley Memorial Aeronautical Laboratory for further tests.

All the pentanes, hexanes, heptanes, and octanes of interest are now on hand. Three nonanes have been isolated from a synthetic crude and partially purified. Synthesis of two additional nonanes, one of which has been prepared once before and one never before, is in progress. Between one and two pounds of a solid octane have been recovered as a byproduct of the synthesis of other materials. This melts at 101° C., boils at 106° C., and is very soluble in liquid paraffin hydrocarbons.

A study is being made to find a suitable scale for rating pure compounds which have octane numbers above 100. Various methods of extrapolation by means of an engine characteristic such as compression ratio on manifold pressure have been considered. However, the best proposal appears to be the use for the present of heptane and iso-octane, each containing 0.1 percent tetraethyl lead, as the primary reference fuels. Secondary reference fuels, one of which is technical iso-octane, also containing 0.1 percent tetraethyl lead would be calibrated against the primary scale and used in testing. This choice of a primary scale is dictated by the consideration that such a scale, composed of pure compounds, can always be duplicated and hence the ratings can in the future be translated into any other scale subsequently adopted merely by



intercomparison of the two sets of scale constituents. Experimental work on this proposed scale is in progress.

**Stability of aviation oils.**—Last year a laboratory test for oil stability was developed at the National Bureau of Standards and mentioned in the report as in satisfactory accord with changes taking place in the oils during service operation of aircraft engines. This correlation was subsequently extended to include all available information on engine deposits both in service and in test-stand operation. It appears that it is possible by means of a simple laboratory test method to predict not only the extent of the changes which will take place in an oil during service operation in aircraft engines but also to predict the extent of deposits which are formed in these engines.

For the information of the military services, a survey has been started on the stability characteristics of commercial aviation oils and it is planned to keep this survey up to date as new or improved aviation oils are developed.

Through the cooperation of the Research Committee on Aircraft Engine Lubricants of the Society of Automotive Engineers, a set of engine inspection forms has been developed for recording the condition of aviation engine parts at the time of overhaul with particular reference to those parts on which deposits form and to those parts in which differences in lubrication characteristics of the oil are important. This makes it possible for all observers to record data on engine conditions on a uniform and comparable basis.

**Ring sticking with aviation oils.**—Further information has been obtained at the National Bureau of Standards on the thickening of oils at the high temperatures encountered around the upper piston rings, and a simple laboratory test method has been developed which has significance as regards the tendency of oils to cause cold ring sticking. During the course of the extensive engine inspections undertaken in connection with the oil stability program, information was obtained regarding the extent of ring sticking. Comparison of the laboratory and engine data on these oils showed that the laboratory data correlated satisfactorily with the extent of ring sticking in service.

The conclusions reached in the investigation of oil stability and cold ring sticking favor highly solvent refined lubricating oils and work is under way to provide protection against serious difficulties with hot ring sticking and with excessive engine wear which may result if over-refined oils are used. It is expected that suitable test methods of protection against the use of over-refined oils will be available during the coming year.

**Corrosion.**—A new laboratory method of determining the corrosiveness of oils has been developed. It has been determined that corrosion due to oil in engines is critically affected by the preparation of the sliding surfaces during manufacture.

**Bearing corrosion.**—Considerable progress has been made at the National Bureau of Standards in the investigation of the problem of the corrosion of master-rod bearings. The general trend of the investigation has been to evaluate the critical temperatures at which oils form corrosive acids, and marked differences have been found between various oils in this respect. This work is rapidly approaching the stage where a significant laboratory test method can be proposed.

In the course of the corrosion work, it was found that there were appreciable differences between the results obtained by different laboratories in the determination of the neutralization number of used aviation oils. Accordingly, through the cooperation of the Research Committee on Aircraft Engine Lubricants of the Society of Automotive Engineers, a modified method for the determination of neutralization number was developed which was found to give reproducible values in different laboratories. A description of this method has been published by the American Society for Testing Materials in its annual report.

**Lubrication of master-rod bearings.**—A small bearing machine has been developed at the National Bureau of Standards for the investigation of master-rod bearing lubrication under severe operating conditions. This machine uses four small bearings similar metallurgically and in surface composition to full-scale bearings. It is possible to operate the machine over a wide range of speeds, loads, and oil temperatures. Information thus far obtained indicates that the machine is very satisfactory and that the load-carrying capacities of bearing materials can be rapidly and accurately evaluated.

## REPORT OF COMMITTEE ON AIRCRAFT MATERIALS

### SUBCOMMITTEE ON METALS USED IN AIRCRAFT

**Effect of continuous weathering on aircraft metals.**—Aircraft structural parts built up of sheet-metal members are used very extensively. The development of the monocoque or stressed-skin type of airplane structure has served to emphasize strongly the importance of the durability of sheet metal. The effect of continuous exposure to weathering action is a factor which must always be considered.

Technical Report No. 663, "The Weathering of Light Metal Alloys Used in Aircraft," has been published.

This summarizes the results of extensive outdoor exposure tests of 5 years' duration previously carried out on aluminum and magnesium alloys in sheet form, of various commercial compositions and with various types of protective surface treatments and applied coatings.

A report is being published which summarizes the results obtained during the first year in the current series of exposure tests on aircraft metals. This covers aluminum and magnesium alloys and stainless steel, all in sheet form. In one series of tests the materials are exposed continuously in a marine atmosphere, Hampton Roads Naval Air Station, and in a supplementary series the materials are so placed as to be immersed in sea water at high tide. In these exposure tests emphasis has been placed on the determination of the effects on various types of metals when in contact one with another in both riveted and welded joints.

This series of tests, which was planned to extend over a period of several years, is an "open" one in that new materials of promise can be included as they become available. At the request of the manufacturers, an aluminum alloy, the commercial standing of which had been established by usage over a number of years, was included in the test, and arrangements are in progress for the inclusion of a recently developed material of unusual promise, although it is not yet commercially available. Only by prolonged exposure tests of this kind can the merits of such materials for aircraft use be established.

**Elastic properties of high-strength constructional aircraft metals.**—Technical Report No. 670, "Tensile Elastic Properties of 18:8 Chromium Nickel Steel as Affected by Plastic Deformation," has been published. A second report entitled "Tensile Elastic Properties of Typical Stainless Steel and Nonferrous Metals as Affected by Plastic Deformation and by Heat Treatment," is being prepared for publication. This report considers the tensile elastic properties of 18:8 chromium-nickel steel, 18:2 chromium-nickel steel, monel metal, Incomel, and K-monel metal. A general discussion is given of the relationship between stress, strain, and permanent set. Stress-strain relationships are discussed, together with the variation of proof stresses with prior plastic extension; also the influence of work-hardening and internal stress on the form of the proof stress-extension curve. From the stress-strain curves have been derived stress-modulus lines. For all but relatively soft metals, the stress-modulus line is practically straight. Stress deviation, that is, deviation from stress-modulus line, and stress-set curves were determined, and from these were derived various diagrams illustrating the influence of plastic-extension and heat treatment on the elastic strength, on the modulus of elasticity, and on its stress coefficient. Equations have been developed to represent the form of the elastic stress-strain curve.

The next phase of the investigation, the study of the elastic properties at low temperatures ( $-108^{\circ}$  F.) is being started. Steel of the 18:8 chromium-nickel type, the properties of which have already been studied at normal temperature, is the material to be used in this phase of the work.

**Structural changes in aircraft metals occurring as a result of service.**—Service stresses of structural members are, in general, largely of the character known as fatigue stresses. In this investigation, the study of the impact resistance of the metal after it has been subjected to fatigue stressing occupies an important place.

A report entitled "Effect of Service Stresses on Impact Resistance, X-ray Diffraction Patterns, and Microstructure of 25S Aluminum Alloy" has been published, based on a study of the 25S aluminum alloy used extensively for propellers. No outstanding detrimental effects in this material attributable to fatigue stressing were observed.

The second phase of the investigation deals with the impact properties of normalized SAE X4130 steel (0.30 C, 1.00 Cr, 0.20 Mo) after fatigue stressing below the point at which incipient failure can be detected. Tensile impact tests of smooth unnotched specimens after being fatigued-stressed by axial loading have shown: (a) only slight difference in the tensile impact behavior of normalized X4130 steel at  $-32^{\circ}$  C. and at  $+25^{\circ}$  C.; (b) the production of nonductile impact fractures after sufficient numbers of cycles of stress above the fatigue limit; (c) a surface condition of marked significance—microscopic surface ruptures opened by the tensile impact stress, relatively few in number on highly polished fatigue specimens but present in large numbers on specimens for which a slightly coarser polish was used; (d) the fact that removal of a thin surface layer from fatigue-stressed specimens containing these surface ruptures restored their impact resistance to that of similar unstressed (undamaged) specimens, thus indicating that the damage revealed by the check cracks produced by tension-impact is confined to the surface zones. Further work on this subject is in progress.

Transverse impact tests of notched fatigue specimens prestressed in a rotating cantilever-beam fatigue machine showed that the impact resistance of notched specimens at  $-78^{\circ}$  C. was generally one-half to one-fourth of that at normal room temperature, the percentage decrease in low-temperature impact resistance resulting from fatigue being greater than in similar tests at room temperature.

The extent to which a metal structure recovers during periods of rest following intermittent periods of fatigue-stressing is questionable. Definite indication has been obtained of the strengthening of normalized X4130 steel by alternating stressing above the fatigue

limit and resting. A series of rests and runs of rotating-beam fatigue specimens stressed above the fatigue limit resulted in conditioning the specimens so that after a while the specimen could be kept running continuously at the same overstress without further resting. This subject is being studied at greater length.

**Protection of magnesium alloys.**—Marked advance has recently been made in the development of new protective coatings for magnesium alloys. Five are now commercially available which are equal in the corrosion protection which they give to that produced by the anodic treatment in the dichromate-phosphate solution which has hitherto been standard. The improved treatments all involve a final sealing treatment. Only the methods based on anodic treatment, however, are applicable to all types of magnesium alloys. The use of hydrofluoric acid, which is an essential feature of some of the new treatments, is objectionable for several reasons in the practical application of the coatings, and efforts are being continued to eliminate its use.

**Effect of subzero temperatures on aircraft metals.**—The fact is well established that the lowering of the impact resistance of metals at low (subzero) temperatures is the most marked change in the properties of a metal structure which should be guarded against. In cooperation with the Bureau of Aeronautics, Navy Department, the investigation of various heat-treatment methods to improve this condition at low temperature has been continued but so far without complete success. Indications have been obtained that certain heats of steel are consistently superior to other heats of the same nominal composition but the underlying factors are as yet not clearly understood. The impact resistance at normal room temperature is no criterion of this property at subzero temperature. In the case of welds the seriousness of this condition of low impact resistance at low temperatures is augmented by defects incidental to variations in welding technique. The investigation is being continued.

**Commercial aircraft steel tubing.**—In cooperation with the Bureau of Aeronautics, Navy Department, extensive tests have been carried out in seamless steel aircraft tubing (chromium-molybdenum steel, SAE X4130) obtained from all the available domestic sources of supply. Differences of considerable magnitude in the ultimate tensile strength and the yield strength as compared with the requirements set forth in the specifications of the Navy Department for this type of material were found, this being true for practically all of the manufacturers represented. These differences are apparently the results of differences in fabrication and heat-treatment procedures, since they could be practically eliminated by annealing. A change in the specification requirements may be the logical outcome.

#### SUBCOMMITTEE ON MISCELLANEOUS MATERIALS AND ACCESSORIES

The work of this subcommittee during the past year has been devoted chiefly to the development of plastic material for aircraft structures. A considerable amount of work has also been done on a continuation of the study of flexible transparent window materials, on the compilation of information about acoustical and thermal insulating materials, and on a study of the properties of the new synthetic fiber and glass with a view toward their utilization in parachute and wing fabrics.

Some consideration has been given to the finding of a substitute for silk for shroud lines, the development of more satisfactory shock-strut guards and fluids, pre-rotation of wheels, and safety tires. Work is under way on the development of fillers for small surface depressions such as rivet heads in wings.

The subcommittee is following with interest the work at Langley Field on the development of de-icers and the cooperative work of the Civil Aeronautics Authority at the National Bureau of Standards on the fire-resistance of aircraft materials. On request, a soap manufacturer is now trying to develop a better soap for cleaning airplanes.

**Development of plastic material for aircraft structures.**—Eighteen synthetic resins have been tested to determine their suitability for impregnating and bonding wood veneers to form a reinforced plastic of the requisite strength and stability for use in aircraft construction. Nine hot-pressed and three cold-pressed phenol-formaldehyde resins, one phenol-furfural resin, four urea-formaldehyde resins and one vinyl acetal resin were investigated. Great differences were observed in the temperatures and pressures required for obtaining satisfactory bonds with these resins and in their degree of resistance to delaminating when alternately wetted and dried. On the basis of these data three of these resins have been selected for use as bonding and impregnating agents in the preparation of laboratory samples of reinforced plastics for strength tests. These are a phenol-formaldehyde resin which requires hot pressing to obtain a good bond and cure, a phenol-formaldehyde resin which cures at room temperature by catalytic action, and a vinyl acetal resin which is permanently thermoplastic and requires heat to make it flow and effect a bond. These are representative of the resins required for investigating three different methods of molding reinforced plastics, namely (1) use of heat and pressure accompanied by thermal curing of the resin, (2) application of pressure at room temperature accompanied by catalytic curing of the resin, and (3) use of heat and pressure with a permanently fusible resin. The preparation of curved and tubular speci-

mens by methods adaptable to the fabrication of large members is now being investigated.

Tensile and compressive strength, modulus of elasticity, and water absorption have also been determined for a number of plastics which have been proposed by various commercial sources for use in building propellers, floats, spars, wings, and fuselages of airplanes. The reinforcing agents in these products included wood veneer, pressed wood, flax, jute, and sisal. The results obtained indicate that maximum strength and stiffness is attained with well-oriented fibers and thermosetting resins.

**Evaluation of new transparent plastics as windshields for aircraft.**—The past year has been a period of particularly active development of new transparent plastics, including such materials as cellulose acetopropionate, cellulose acetobutyrate, vinyl chloride-acetate resin, and polystyrene resin. Further improvement in the methyl methacrylate and cellulose acetate plastics has also been effected. An accelerated aging test developed in the course of experimental work on transparent plastics has proved to be a very useful means of rapidly evaluating these new materials with regard to weathering resistance. It is highly desirable that these new and improved materials, which are found to possess the necessary weathering resistance, should be examined with respect to other properties of importance in connection with their use as aircraft windshields and that a specification should be prepared to permit the procurement of transparent plastics which will most satisfactorily meet aircraft requirements.

It is, therefore, proposed to obtain from the respective manufacturers new samples of the transparent plastics which have been found to be outstanding with respect to weathering resistance and to submit them to tests for the following properties: Light transmission, haze, distortion, scratch resistance, impact strength, tensile strength, flexibility, thermal expansion, dimensional stability including both shrinkage and warping, flame resistance, and resistance to action of water, oil, gasoline, grease, and soap solution. The relative resistance of these plastics to weathering will also be established by exposing them in the accelerated aging apparatus for a longer time than the 500 hours which we now use to evaluate outdoor stability. The effect of weathering, both natural and accelerated, on the strength and optical properties of the plastics will be determined. The variation of the strength properties with temperature will be studied over the range from 140° F. to -40° F. A detailed specification will be prepared on the basis of these experimental procedures and results, to cover those materials which are found to be superior for aircraft use.

## REPORT OF COMMITTEE ON AIRCRAFT STRUCTURES

### LANGLEY MEMORIAL AERONAUTICAL LABORATORY

#### STRUCTURAL RESEARCH

One of the problems that has confronted designers of stressed-skin and monocoque structures for several years has been the proportioning of intermediate frames and ribs. Heretofore very little consideration has been given to this problem in the literature. During the past year, two investigations of this problem were undertaken. The first was concerned with the loads on intermediate frames and the second was concerned with the stiffness required of these members. In practical design problems, it is desirable to check both the strength and the stiffness of the intermediate frames.

**Loads on intermediate frames.**—If the flange members of a beam change direction at an intermediate frame, a force is applied to the intermediate frame. This change of direction can either be built in or result from the deflection of the beam.

The practical design formulas for calculating the load on intermediate frames for each of these cases have been summarized in Technical Note No. 687. In this paper, an analysis of diagonal-tension effects in beams with curved webs is also included and a new semi-empirical formula for the loads on the stiffeners is proposed.

**Stiffness required of ribs.**—In the design of stressed-skin wings, it is common practice to assume that the shear webs and ribs are equivalent to rigid supports which divide the stiffened-skin covering into small panels and that the bending strength of the wing depends upon the compressive strength of these panels. This assumption is sound provided the ribs are sufficiently stiff. A first paper on this subject was presented to the Institute of Aeronautical Sciences during the past year. This paper, entitled "On the Rib Stiffness Required for Box Beams," appears in the Journal of the Aeronautical Sciences, May 1939. In this paper the stiffness required of the ribs to divide the compression side of a stressed-skin wing into small panels of length equal to the rib spacing is discussed.

This problem has been further studied and the theory is being extended. This subject is considered one of great importance because, if the ribs of a stressed-skin wing do not have a stiffness equal to or greater than that required to divide the compression surface as assumed, the foundation of the present design procedure crumbles.

**Stress distribution in monocoque structures.**—The stress distribution in monocoque structures is influenced by several factors, one of the most important of which is the shear deformation of the skin. In most practical

cases, the problem of taking shear deformation into account leads to quite laborious methods of analysis. During the past year, a simple numerical method applicable to these problems, as well as to mathematically related problems, has been developed. This method is completely described in Technical Note No. 704, which also includes a practical example.

Continued efforts are being made to find the simplest possible method of solving increasingly complex problems in stress distribution. A continuous check on the validity of the simplifications is being made by strain-gage tests.

**Shell analysis and the shear center.**—There has been some confusion as to how established methods of analysis should be applied to shell structures when the loading consists of combined bending and torsion. The basic principles for this analysis have been established for some time. A summary of the practical design formulas has been made and their use illustrated with a number of problems. The summary and problems have been presented in Technical Note No. 691. In this note it is also pointed out that the use of the shear center offers no advantage over the use of any arbitrary reference point.

**Method of estimating critical loads.**—In most problems of elastic instability the critical buckling load is determined by satisfying certain transcendental equations associated with the condition of neutral stability. In order to solve these equations, it is necessary to assume values of the critical load and to test the equations. By application of methods similar to those proposed by Southwell for the analysis of experimental observations in problems of elastic stability, a method has been developed to estimate quickly the theoretical critical load after the equation for neutral stability has been tested for three assumed critical loads. This method of estimating critical loads, as applied to structural members, has been described in Technical Note No. 717. In this paper a number of examples are given to reveal certain characteristics of the method that should be known by the practical engineer using it.

**Local buckling of compression members.**—During the past year two papers (Technical Notes Nos. 686 and 722) have been published wherein charts are presented for the coefficient in the formula for critical compressive stress at which cross-sectional distortion begins in columns with rectangular-tube, channel, and Z-sections. This work is being extended to include much more comprehensive treatments for buckling problems in general.

**Correlation of structural data.**—During the past year, the Committee has received a large amount of structural-test data from the Army Air Corps, the Bureau of Aeronautics of the Navy, the Civil Aeronautics Au-

thority, and the aircraft industry. These data are being studied with a view to correlating as much of it as possible. Steps are being taken to supplement present information with regard to the geometric dimensions of the test specimens, the material properties, and the types of failure.

A valuable result of the study of these data has been to observe what problems have not been attacked by the industry. This information has been used to revise the structural-research programs of the Committee so as to cover important phases of structural design for which information is needed.

#### STRUCTURAL LOADS ON AIRPLANES

**Statistical measurements of gust loads.**—Coordinated measurements of acceleration and air speed on transport airplanes have been continued. Although several high accelerations have been recorded during the past year, none of them exceed the maximums previously recorded. This subject is more fully presented under the report of the Subcommittee on Meteorological Problems.

**Gust structure.**—An investigation of gust structure under a variety of weather conditions and at various altitudes up to 17,000 feet in the vicinity of Langley Field has been concluded. Analysis of the complete data has led to verification of earlier indications that there is no correlation between gust intensity and gust gradient. In the case of gusts encountered in the lower levels of the atmosphere, a fairly high degree of correlation was found to exist between the wind gradient and a gust-intensity index derived from an elementary analysis based on the concept that gusts arising from mechanical friction or disturbances behave in a manner analogous to the behavior of a simple elastic system. In the case of thermal gusts, the maximum intensities measured during surveys of the gust occurring in different weather situations were found to be dependent on the thermal energy available for convection in these situations.

The indications obtained from gust measurements on a number of airplanes of widely different size, considered in conjunction with tests in the gust tunnel, have led to improved working concepts of the relation between maximum gust intensities and corresponding gradients. Although the subject is too involved to discuss here, for practical design purposes there are strong indications that the gradient distance of the gust may be taken as 8.5 chord lengths. Currently used gust factors derived on a somewhat different basis are not in disagreement with this concept and, in fact, have been more firmly established by the more recent data. Recent advances in the theory of unsteady flow likewise do not upset in any way the practical value of the established gust-load criterions.

**Gust tunnel.**—The results of the first tests in the gust tunnel, reported last year, have been published in Technical Note No. 706.

Tests of a biplane model (Technical Note No. 731) indicate that, when the conventional assumption of the equivalent monoplane is made, calculated accelerations are considerably less than the measured values (20 percent in the case tested). If the wings are assumed to act independently as finite monoplanes, however, agreement between calculated and test results is good, provided the gradient distance does not exceed about 10 to 12 chord lengths. Beyond this distance, a discrepancy appears that is probably due to an increasing approach to steady-flow conditions, with a corresponding increase in induced biplane interference.

Tests on a model of a "canard," or "tail-first," airplane designed to be the equivalent of a particular conventional airplane showed that the "canard" arrangement is unfavorable from considerations of gust loads. In the case studied, the accelerations were about 30 percent higher than those measured on the conventional model throughout the important range of gust gradients.

In order to determine the possibility of reducing gust accelerations by suitable structural design of the wing, a model was provided with a wing flexible in torsion. This wing was tapered, the tip chord being half the root chord, and the construction was such that the tip section twisted  $-1.5^\circ$  per load factor with properly distributed load. Comparative tests on the model alternately equipped with the flexible wing and with a rigid wing indicated that the effect of the flexibility was a reduction in acceleration approximately proportional to the gradient distance and having a value of about 16 percent with a gradient distance of 10 chord lengths.

**Load distribution.**—An analytical study of the variation of the net wing loads under conditions in which combined angular and normal accelerations exist has been completed. This study included the determination of the shear and the moment variation along the wing span during unsymmetrical landings, aileron deflection, and several types of unsymmetrical gusts. The results are being applied in a report, now in preparation, to illustrate the effect of a number of variables such as wing taper, wing weight, and aileron span on the shears and moments.

**Tail loads.**—The possibility of relating tail loads and load factors in maneuvers has been given considerable attention. Within the past year a set of dynamometer springs has been designed and installed in a small airplane for measuring tail loads. Special apparatus for controlling rate and amount of elevator deflection and other equipment has also been installed.

A brief analysis of the loads on horizontal tail surfaces during recovery from spins indicates that for large modern multiengine airplanes there is considerable danger of failure in this condition. The loads become excessive because of high rates of descent resulting from heavy wing loading, clean design, and steep spinning attitude and because the tail operates at maximum lift coefficient while passing from the stalled state of the spin to the unstalled state following recovery. In one case investigated, the upward-acting tail load during recovery was estimated to be several times the normal design load. Wing loads may also be excessive on large modern airplanes in spins.

Measurements of gust loads on the vertical tail surfaces of a twin-engine airplane have been concluded. The results indicate no simple basis for relating the probable gust loads on tail surfaces to the gust loads on the wings, because the tail loads in rough air are a summation of partial loads caused by the direct action of the gust, the angle of the rudder, the yawing velocity of the airplane, and possibly the position of the surface relative to the slipstream determined by yawing of the airplane and irregularities in the slipstream caused by atmospheric turbulence. In order to study these conditions more fully, as well as to obtain further statistical data, more complete instrumentation has been installed in a modern four-engine airplane.

**Loads on seaplane hulls.**—Extensive measurements of hull pressures, stresses, and acceleration on two large flying boats have been completed. The results have given a fairly complete qualitative picture of the nature of the loading conditions. They indicate that forward speed plays a predominant part in determining the magnitude of the maximum pressures and that, at a given speed, the maximum pressures may be of the same value at any point on the bottom, the position in any case depending on the attitude of the hull and the conformation of the water surface. These maximum pressures are usually so localized and shift position so rapidly that they are of little direct structural significance, although under some circumstances in rough water the areas involved may be great enough to give rise to high local loads. In regard to the resultant load on the hull, the vertical momentum is of more importance, inasmuch as it determines the depth of immersion and consequently the wetted area over which the mean pressure acts. For example, on a given hull at constant vertical velocity the acceleration was found to increase with beam loading (vertical momentum) because of the increased wetted area.

**Dynamic overstress.**—Measurements of acceleration and wing stress have been made on a very large airplane in rough air. The results agree with those pre-



viously obtained on an M-130 flying boat in indicating no evidence of dynamic overstress. Measurements of acceleration and wing stress have also been made on a small airplane in maneuvers to demonstrate that the relation between load factor and stress remains the same regardless of the period of application of load under all possible conditions.

#### NATIONAL BUREAU OF STANDARDS

**Tensile and compressive properties of duralumin, magnesium, and alloy steels.**—A paper describing the pack method for compressive tests of thin sheet metal has been published during the past year as Technical Report 649.

The pack method was extended to thinner gages and to higher compressive stresses in order to obtain compressive stress-strain curves for 0.02-inch stainless-steel sheet material for the Bureau of Aeronautics, Navy Department. Additional support was obtained by cementing the leaves of the pack together with shellac and by using external clamps of special design. It was possible with this procedure to apply stresses up to 202 kips per square inch to a pack of about 31 leaves of 0.02-inch stainless-steel sheet before failure occurred by sudden instability of the entire pack.

Column tests and crinkling tests were made on closed sections formed from this material by spot-welding with the load along the direction of rolling in the case of half of the specimens and at right angles to the direction of rolling in the case of the other half. The tests showed differences in strength that agreed with the differences expected from the compressive stress-strain graphs.

A number of tests were made to develop a convenient and rapid method for detecting the presence of aeolotropy in compressive properties of thin sheet. The most promising results were obtained by comparing the buckling loads obtained in fixed-end compressive tests of single strips of suitable length cut from the sheet in a transverse and a longitudinal direction. In the case of stainless-steel strips having a length equal to about 20 times their thickness the transverse buckling load exceeded the longitudinal buckling load by about 50 percent.

**Beryllium.**—Mechanical tests have been made on a number of specimens of beryllium aluminum alloy with a beryllium content from 22.6 to 70 percent (nominal). The Young's modulus for these specimens ranged from 14,800 to 30,000 kips per square inch. Tensile tests resulted in a highly curved stress-strain curve in each case, a tensile yield strength (offset, 0.2 percent) ranging from 15.5 to 20.2 kips per square inch, a tensile strength ranging from 22.8 to 29.1 kips per square inch, and an elongation in 1 inch ranging from 2.0 to 9.0 percent.

**Flat plates under normal pressure.**—The tests of circular plates with clamped edges have been completed and a detailed report has been submitted to the Bureau of Aeronautics, Navy Department. Normal-pressure tests were made on 19 plates 5 inches in diameter ranging in thickness from 0.0149 to 0.0723 inch. Seventeen of the plates consisted of aluminum alloy, one of 18:8 stainless steel and one of magnesium alloy.

The center deflections and stresses at low pressures were found to agree with those calculated for a plate of "medium thickness" from theories by Way and Nadai. At higher pressures the observed center deflections exceeded the calculated values consistently by 4 to 12 percent. With the beginning of permanent set at the center both the total center deflection and the permanent set at the center tended to increase linearly with the pressure for most of the plates.

The pressure required to produce yielding in the plate, as measured by a given permanent set at the center, was between the theoretical pressures for yielding at the edge and for yielding at the center of the plate. Empirical curves are included in the report which relate the pressures for a given permanent set at the center of the plate to the dimensions of the plate and the tensile properties of the material.

**Aircraft tubing.**—The first portion of the program on high-strength chromium-molybdenum-steel tubing of the type used in landing gears was completed by tests in tension, compression, bending and torsion of tubes whose diameter-thickness ratio ranged from 12 to 55.

The tests were complicated by the extreme hardness of the material which caused difficulties in seating strain gages and gripping the specimens for test, and by variations in properties in the individual lengths of tubing. However, these difficulties were overcome and enough tests were made so that the strengths are known sufficiently well in terms of the diameter-thickness ratios and the mechanical properties of the material to proceed with tests under combined loading.

**Wing beams.**—Detailed reports were prepared for the Bureau of Aeronautics, Navy Department, on tests of two series of wing beams under axial loads, transverse loads, and combined axial and transverse loads. The materials were 24ST aluminum alloy in both cases, and the section was an I-section having curved flanges for one series and tilting flanges for the other.

The reports include a stiffness-weight and a strength-weight comparison with the wing beams previously tested for this project (stainless-steel box beams, 17ST and 24ST aluminum-alloy I-beams with straight flanges). For combined axial and transverse loads the strength-weight ratio for all beams tested to date was found to be roughly the same at a slenderness ratio of about 40.

**Sheet-stringer panels.**—A report of end-compression tests of nine aluminum-alloy sheet-stringer panels was submitted to the Bureau of Aeronautics, Navy Department.

The report gives the results of tests on a series of panels reinforced by three Z-stringers that were fastened to the sheet by brazier-head rivets spaced from 0.5 to 6 inches between centers. Four of the panels failed by separation of rivets at a stringer stress of 24.2 to 39.5 kips per square inch. The remaining panels failed by instability of the stringers at a stringer stress from 38 to 42 kips per square inch.

The observed effective widths of the sheet were from -1 to 20 percent greater than the effective widths calculated from Marguerre's formula for simply supported edges up to an edge strain at which buckling occurred between rivets. The sheet load remained approximately constant after buckling of the sheet between rivets.

**Monocoque boxes.**—The monocoque box specimen, the elastic deformation of which under axial load and under various types of transverse loading is to be studied, has been tested in compression. The test data have been analyzed and the results have been described in Technical Note No. 721.

**Strength of riveted joints in aluminum alloy.**—A report on tests of single rivet joints embodying flush rivets

has been prepared for the National Advisory Committee for Aeronautics. The report gives the results of static tests in single shear, in double shear, and in tension of 865 joints prepared by seven different aircraft manufacturers, the Naval Aircraft Factory, and the National Bureau of Standards. A series of graphs is included to show directly the relation between the shearing stress, bearing stress, and diameter-thickness (rivet diameter to sheet thickness) ratio for all the single shearing joints tested.

**Fatigue testing of aluminum-alloy wing beams.**—The third wing beam has been tested to failure in fatigue. The test showed progress toward the solution of certain problems in technique which must be solved whenever structures similar to wing beams are tested by the resonance method under axial loads.

The results for the first two beams tested indicate approximately equal resistance to fatigue throughout the length of each beam, but in the third beam a crack had traversed the web at the edge of the reinforcement near the center of the beam before much more than half the total number of cycles had been completed. This local failure of the web, however, did not lead to final failure of the beam. Cracks later appeared at other points of stress concentration and the final failure was similar to that of the other two beams.



## PART II

### ORGANIZATION AND GENERAL ACTIVITIES

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#### ORGANIZATION

The National Advisory Committee for Aeronautics was established by act of Congress approved March 3, 1915, and the membership increased from 12 to 15 by act approved March 2, 1929 (U. S. C., title 50, sec. 151). Its membership is appointed by the President and consists of two representatives each of the War and Navy Departments from the offices in charge of military and naval aeronautics, two representatives of the Civil Aeronautics Authority (Civil Aeronautics Act of 1939), one representative each of the Smithsonian Institution, the United States Weather Bureau and the National Bureau of Standards, together with six additional persons who are "acquainted with the needs of aeronautical science, either civil or military, or skilled in aeronautical engineering or its allied sciences." These latter six serve for terms of 5 years. All the members serve as such without compensation. During the past year the following changes occurred in the membership of the main Committee:

Dr. Francis W. Reichelderfer, the new Chief of the United States Weather Bureau, was appointed a member on January 2, 1939, to fill the vacancy occasioned by the death on September 14, 1938, of Dr. Willis Ray Gregg, Chief of the United States Weather Bureau.

Brigadier General George H. Brett, United States Army, Chief of Matériel Division, of the Army Air Corps, Dayton, Ohio, was appointed a member of the Committee on March 11, 1939, to succeed Brigadier General Augustine W. Robins, United States Army, relieved because of transfer to other military duty.

Honorable Robert H. Hinckley, Chairman of the Civil Aeronautics Authority, was appointed a member of the Committee, May 20, 1939, to succeed Honorable Edward J. Noble, who had resigned as Chairman of the Civil Aeronautics Authority.

Rear Admiral John H. Towers, United States Navy, was appointed a member on May 20, 1939, effective June 1, 1939, on which date he succeeded Rear Admiral Arthur B. Cook, United States Navy, as Chief of the Bureau of Aeronautics, Admiral Cook having been transferred to sea duty.

Dr. George J. Mead, of West Hartford, Conn., was appointed from civil life a member of the Committee, on October 11, 1939, to fill out the unexpired term of Dr. Joseph S. Ames, who resigned on October 7 because

of physical inability to take an active part in the work of the Committee. Dr. Ames had served as a member of the Committee since its establishment in 1915. At the time of his resignation, he was Chairman of the Committee and was serving under a 5-year appointment by President Roosevelt, expiring December 1, 1943. Comment on Dr. Ames' service appears in the opening portion of this report.

Under the rules and regulations governing the work of the Committee, as approved by the President, the Chairman and Vice Chairman are elected annually, as are also the Chairman and Vice Chairman of the Executive Committee. On October 19th, 1939, Dr. Vannevar Bush, who had served as Vice Chairman of the main Committee and Chairman of the Executive Committee, was elected Chairman of the main Committee to succeed Dr. Ames. Dr. George J. Mead was elected Vice Chairman of the main Committee. Dr. Bush was also elected Chairman of the Executive Committee and Dr. Charles G. Abbot, Vice Chairman of the Executive Committee.

The executive offices of the Committee, including the office of aeronautical intelligence and the office of aeronautical inventions, are located in the Navy Building, Washington, D. C., in close proximity to the air organizations of the Army and Navy.

The office of aeronautical intelligence was established in the early part of 1918 as an integral branch of the Committee's activities. It serves as the depository and distributing agency for the scientific and technical data on aeronautics comprising the results of fundamental Committee researches and also the scientific and technical information collected by the Committee from governmental and private agencies in this country and abroad. The data collected are classified, cataloged, and disseminated by this office.

The Committee's technical assistant in Europe, Mr. John J. Ide, whose headquarters are at the American Embassy in Paris, visits governmental and private agencies in Europe to collect results of researches and to gain first-hand information as to researches proposed and in progress.

#### RESEARCH FACILITIES

With the consistent support of the President and of the Congress, the Committee has developed at Langley

Field, Va., a large and well-equipped aeronautical research laboratory, known as the Langley Memorial Aeronautical Laboratory. Advances to date in the relatively new engineering science of aeronautics have been made possible largely by the design and construction at Langley Field of novel research equipment.

At the present time, the Langley Field Laboratory comprises the following units: The 8-foot 500-mile-per-hour wind tunnel; the full-scale wind tunnel with a throat 60 by 30 feet; the 20-foot propeller-research-tunnel; the 5-foot variable-density wind tunnel; a 7- by 10-foot wind tunnel; a 4- by 6-foot vertical wind tunnel; a 15-foot free-spinning wind tunnel; two high-velocity jet-type wind tunnels of 11- and 24-inch throat diameters, respectively; the 2,900-foot N. A. C. A. tank; an engine-research laboratory; a flight-research laboratory; an instrument laboratory; and administration and service buildings. The research facilities at Langley Field also include the following recent additions: A 19-foot pressure wind tunnel; a refrigerated wind tunnel with a throat 7½ by 3 feet; a 12-foot free-flight wind tunnel; and an additional shop building.

The Committee is proceeding to construct at Langley Field a structures research laboratory, a two-dimensional flow wind tunnel, a stability wind tunnel, a 16-foot high-speed wind tunnel and a 20-foot free-spinning wind tunnel.

The Committee has in process of construction at Moffett Field, Calif., a second major research station, authorized by act approved August 9, 1939. The facts in connection with this vitally important addition to the Committee's research facilities follow.

#### SECOND RESEARCH STATION

At a meeting of the Executive Committee on August 19, 1938, the late Major General Oscar Westover, then Chief of the Army Air Corps, and Chairman of a Special Committee on the Relation of the N. A. C. A. to National Defense in Time of War, recommended that the Committee plan an additional research center somewhere in the interior of the country or on the West Coast, in order to relieve the situation he described as "the congested bottle neck of Langley Field." As a result of this suggestion General Westover's committee was requested to make a study of long-range planning for the location of additional laboratory activities for the Committee away from the present laboratory at Langley Field.

During the following month, General Westover and Dr. W. R. Gregg, two of the three members of the special committee, met untimely deaths, leaving Admiral Cook as the sole surviving member. At the meeting of the main Committee on October 20, 1938, a Special Committee on Future Research Facilities was formed consisting of Rear Admiral Arthur B.

Cook, chairman, Major General Henry H. Arnold, Honorable Edward J. Noble, Dr. Edward Warner, and Dr. George W. Lewis. This committee studied the need for additional research in aeronautics and the problems involved in a long-range plan for future research facilities as related to national defense and to commercial aviation. The committee also studied the need for more effective coordination of aeronautical research among governmental, industrial, and educational institutions. A subsidiary special committee studied the desirable sites for a second aeronautical research station. As a result of these studies the special committee submitted a report on December 30, 1938, recommending the immediate establishment of a second research station at Sunnyvale, Calif., and the construction of the most advanced research equipment at an estimated cost of \$11,000,000. Additional research facilities were recommended for Langley Field, Va., and a plan for the more effective coordination of applied research in industry was outlined as an immediate need.

On February 3, 1939, the President of the United States transmitted to the Congress supplemental estimates amounting to \$6,723,000. Of this amount \$2,140,000 was for new construction at Langley Field, \$36,000 for the proposed coordination plan, \$250,000 for contracts for research in scientific and educational institutions, \$297,000 for salaries and expenses, and \$4,000,000 for construction of facilities at the proposed new Sunnyvale, Calif., research station. Appropriations for salaries and expenses and the new facilities at Langley Field and for the coordination plan were included in the Second Deficiency Act in the total amount of \$2,363,980. Authorization of the second research station was included in the Third Deficiency Act approved August 9, 1939. The act carried a total appropriation of \$2,000,000. Of this amount \$1,890,980 was provided to begin construction of an additional aeronautical research station at a total cost of not to exceed \$10,000,000 upon such site as may be chosen by the National Advisory Committee for Aeronautics from the sites brought to its attention within 30 days after approval of the act.

In all, 54 sites for the proposed station were brought to the attention of the Committee within the 30-day period fixed by law and were referred to the Special Survey Committee on Aeronautical Research Facilities, consisting of Colonel Charles A. Lindbergh, chairman, Major General Henry H. Arnold, Rear Admiral John H. Towers, and Honorable Robert H. Hinckley. The characteristics of each of the 54 sites, as described in the proposals and as supplemented by additional inquiries, were subjected to an exhaustive analysis. Some of the factors which were considered in rating the sites for their approach to the ideal included: The nature of the flying field on which the station was pro-

posed, the adequacy and cost of electric power, proximity to a suitable industrial center, proximity to the aircraft industry, climatic conditions especially as related to year-round flying, military vulnerability, adequate transportation facilities, and working and living conditions for employees. The subcommittee recommended and the Committee decided by a unanimous vote, after due consideration, that all things considered the best interests of aeronautics would be served by the location of the second research station at Moffett Field near Sunnyvale, and 38 miles south of San Francisco, Calif. The decision was announced on September 22, 1939.

The new site consists of approximately 100 acres, 60 of which have been assigned to the Committee by the War Department and 40 purchased. Moffett Field is a former naval air station of 1,000 acres originally used for lighter-than-air activities but now under the administration of and actively used by the Army Air Corps. The Committee will conduct its research activities there under a status similar to that under which it functions at Langley Field. The planning and construction of research facilities and equipment are progressing as rapidly as possible. The Committee's present plans do not contemplate the conduct of engine research at the Moffett Field laboratory.

#### CONSIDERATION OF AERONAUTICAL INVENTIONS

By act of Congress approved July 2, 1926, an Aeronautical Patents and Design Board was established consisting of Assistant Secretaries of the Departments of War, Navy, and Commerce. In accordance with that act as amended by the act approved March 3, 1927, the National Advisory Committee for Aeronautics passes upon the merits of aeronautical inventions and designs submitted to any aeronautical division of the Government, and submits reports thereon to the Aeronautical Patents and Design Board. That board is authorized, upon the favorable recommendation of the Committee, to "determine whether the use of the design by the Government is desirable or necessary and evaluate the design and fix its worth to the United States in an amount not to exceed \$75,000."

During the past year the inventions section received 1,800 inventions and designs pertaining to the aeronautical art. All of these proposals were given careful consideration and evaluated. The necessary correspondence was conducted to advise the submitters of the evaluations and interviews were granted inventors to discuss new proposals and their merits.

#### AERONAUTICAL RESEARCH IN EDUCATIONAL INSTITUTIONS

The Committee has continued to follow the policy initiated as a result of recommendation of the Federal

Aviation Commission, of making available a special allotment of \$25,000 from each year's funds for aeronautical research in educational institutions. Under this allotment during the fiscal year 1939, contracts were made for 12 special investigations and reports at 10 universities and technical schools, on the basis of the probable usefulness and value of the information to aeronautics.

Several of the papers prepared under contracts have been published by the Committee, and in other cases the results obtained in the investigations have supplied a basis for further research. During the past year nine contract reports have been issued as Technical Notes and one as a confidential report to American manufacturers, and six others are now being revised and edited for publication by the Committee.

The Committee has given much consideration to this policy and is strongly of the opinion that its activities in the encouragement and stimulation of aeronautical research in educational institutions should be greatly extended, and has recommended in its estimates for 1941 that the funds for the purpose be increased from \$25,000 to \$250,000. There is a pressing need to marshal the existing scientific resources of the country on a large variety of scientific problems in aeronautics. Furthermore, with the expansion of the air program and intensification of efforts to improve the performance and efficiency of aircraft, and with increased research facilities being made available to the Committee, there will be great need for additional trained research workers in the United States. The training of these workers should be done by educational institutions. Thus this program will accomplish a twofold purpose in supplying new knowledge and in training research workers.

#### COOPERATION WITH THE AVIATION INDUSTRY

In the formulation of its research programs, the Committee includes provision for the problems of aeronautical research which are of particular importance to the aviation industry, in connection with both the design and operation of aircraft. The representatives of the industry refer their problems of this nature to the Committee as they arise, either by correspondence or through personal contact. The Committee avails itself of every opportunity to obtain suggestions and recommendations from representatives of the aircraft manufacturers and operators as to investigations which are of special importance to them.

For the purpose of familiarizing the industry with the research facilities of the Committee and the programs of research under way, there is held at the Committee's laboratory at Langley Field, Va., once a year, usually in May, an aircraft engineering conference. This conference is attended by the representatives of the aircraft manufacturers and operators. Open dis-

cussions are held wherein suggestions are received which lead to modifications or additions to the programs to obtain the information desired. In some cases these suggestions have initiated new programs of research. It is a long-standing policy of the Committee when the need arises in connection with any particular problem of the industry to call a special conference or to appoint a special subcommittee.

Realizing that frequently the value of information is greatly enhanced by its prompt availability, every effort is made to place in the hands of the industry at the earliest possible date the results of researches that are of particular interest in connection with civil aeronautics. It sometimes appears, in the course of an extensive investigation being conducted by the Committee, that the results so far obtained will be of special interest and value to the aircraft industry if made available immediately. In such cases the Committee issues the information in advance confidential form to American manufacturers and the Government services.

#### COORDINATION OF AERONAUTICAL RESEARCH

In order to provide for the more effective coordination of applied aeronautical research in industry and to utilize more effectively research facilities at scientific and educational institutions, the Committee has set up, with funds provided by the Congress for the purpose, a new section on coordination. It is the expectation of the Committee that this new activity will have the following beneficial results: It will accelerate progress in aeronautics by bringing the results of research more directly to the attention of designers and engineers in the aircraft industry, and by bringing more promptly to the attention of the Committee new problems requiring scientific study and investigation; it will utilize existing facilities in scientific and educational institutions on a larger scale than in the past, to the extent that additional funds may be made available for the purpose; and it will stimulate scientific research in such institutions, coordinate applied research in industry, and at the same time serve to prevent unnecessary overlapping and duplication of effort.

This is not a new function of the Committee but is rather an enlargement of an existing function made necessary by the magnitude of the country's air defense program and the need to accelerate progress in the development of American aeronautics, in order that the performance of American aircraft may equal or excel the performance of the aircraft of any other nation. The new section on coordination will operate under the immediate supervision of a coordinator of research, who will be a member of all the standing technical subcommittees and who will have assistants

in the field keeping in close touch with the progress and needs of aeronautical science by visiting the aircraft industry and scientific and educational institutions.

#### SUBCOMMITTEES

The National Advisory Committee for Aeronautics has organized standing technical committees, with subcommittees, for the purpose of coordinating the research needs of aviation and preparing research programs in their respective fields. The four main technical Committees on Aerodynamics, Power Plants for Aircraft, Aircraft Materials, and Aircraft Structures and their subcommittees prepare the programs for the aeronautical research conducted by the Advisory Committee and coordinate the investigations conducted by other agencies.

As previously stated, it is the policy of the Committee to establish from time to time special technical subcommittees for the study of particular problems as they arise, and several such special subcommittees have been organized.

The work of the standing technical committees and subcommittees has been described in part I. Their organization, together with that of the special technical subcommittees, is as follows:

#### COMMITTEE ON AERODYNAMICS

Dr. Edward Warner, Chairman.  
 Dr. George W. Lewis, National Advisory Committee for Aeronautics, Vice Chairman.  
 Dr. L. J. Briggs, National Bureau of Standards.  
 Maj. F. O. Carroll, Air Corps, United States Army, Matériel Division, Wright Field.  
 Comdr. W. S. Diehl, United States Navy.  
 Dr. H. L. Dryden, National Bureau of Standards.  
 John Easton, Civil Aeronautics Authority.  
 Mr. J. T. Gray, Civil Aeronautics Authority.  
 Maj. Carl F. Greene, Air Corps, United States Army, Matériel Division Liaison Officer at N. A. C. A. Laboratories.  
 Delbert M. Little, United States Weather Bureau.  
 Maj. Alfred J. Lyon, Air Corps, United States Army, Matériel Division.  
 Elton W. Miller, National Advisory Committee for Aeronautics.  
 Comdr. F. W. Pennoyer, Jr., United States Navy.  
 H. J. E. Reid, National Advisory Committee for Aeronautics.  
 Comdr. Leslie C. Stevens, United States Navy.  
 Mr. Omer Welling, Civil Aeronautics Authority.  
 Dr. A. F. Zahm, Division of Aeronautics, Library of Congress.

#### SUBCOMMITTEE ON AIRSHIPS

Dr. J. C. Hunsaker, Chairman.  
 Starr Truscott, National Advisory Committee for Aeronautics, Vice Chairman.  
 John Easton, Civil Aeronautics Authority.  
 Captain Garland Fulton, United States Navy.  
 Maj. C. F. Greene, Air Corps, United States Army, Matériel Division Liaison Officer at N. A. C. A. Laboratories.  
 Dr. George W. Lewis, National Advisory Committee for Aeronautics (ex-officio member).

## SUBCOMMITTEE ON METEOROLOGICAL PROBLEMS

Dr. F. W. Reichelderfer, United States Weather Bureau, Chairman.

Col. E. S. Gorrell, Air Transport Association of America.  
 Dr. W. J. Humphreys, United States Weather Bureau.  
 Dr. J. C. Hunsaker, Massachusetts Institute of Technology.  
 R. W. Knight, Civil Aeronautics Authority.  
 Dr. George W. Lewis, National Advisory Committee for Aeronautics (ex-officio member).  
 Delbert M. Little, United States Weather Bureau.  
 Comdr. Wilber M. Lockhart, United States Navy.  
 Capt. R. M. Losey, Air Corps, United States Army.  
 Dr. Charles F. Marvin.  
 Mr. Richard V. Rhode, National Advisory Committee for Aeronautics.  
 Dr. C. G. Rossby, United States Weather Bureau.

## SPECIAL SUBCOMMITTEE ON LIGHTNING HAZARDS TO AIRCRAFT

Delbert M. Little, United States Weather Bureau, Chairman.  
 J. C. Franklin, Transcontinental & Western Air, Inc.  
 Dr. O. H. Gish, Carnegie Institution of Washington.  
 Commander L. M. Grant, United States Navy.  
 Charles H. Helms, National Advisory Committee for Aeronautics.  
 Dr. George W. Lewis, National Advisory Committee for Aeronautics (ex-officio member).  
 K. B. McEachron, General Electric Company.  
 Irving R. Metcalf, Civil Aeronautics Authority.  
 Capt. C. K. Moore, Air Corps, United States Army, Matériel Division, Wright Field.  
 Dr. F. B. Silsbee, National Bureau of Standards.

## SUBCOMMITTEE ON SEAPLANES

Dr. J. C. Hunsaker, Chairman.  
 Theophile dePort, Matériel Division, Army Air Corps, Wright Field.  
 Commander W. S. Diehl, United States Navy.  
 J. T. Gray, Civil Aeronautics Authority.  
 Dr. George W. Lewis, National Advisory Committee for Aeronautics (ex-officio member).  
 Capt. C. K. Moore, Air Corps, United States Army, Matériel Division, Wright Field.  
 A. L. Morse, Civil Aeronautics Authority.  
 Capt. H. C. Richardson, United States Navy.  
 Starr Truscott, National Advisory Committee for Aeronautics.

## SPECIAL SUBCOMMITTEE ON VIBRATION AND FLUTTER

H. J. E. Reid, National Advisory Committee for Aeronautics, Chairman.  
 Capt. Frederick R. Dent, Jr., Air Corps, United States Army, Matériel Division, Wright Field.  
 Comdr. W. S. Diehl, United States Navy.  
 Comdr. L. M. Grant, United States Navy.  
 Charles H. Helms, National Advisory Committee for Aeronautics.  
 Dr. George W. Lewis, National Advisory Committee for Aeronautics (ex-officio member).  
 Comdr. R. D. MacCart, United States Navy.  
 Irving R. Metcalf, Civil Aeronautics Authority.  
 Ford Prescott, Matériel Division, Army Air Corps, Wright Field.  
 Dr. Walter Ramberg, National Bureau of Standards.  
 Edward I. Ryder, Civil Aeronautics Authority.  
 Benjamin Smilg, Matériel Division, Army Air Corps, Wright Field.

Dr. Theodore Theodorsen, National Advisory Committee for Aeronautics.

## COMMITTEE ON POWER PLANTS FOR AIRCRAFT

Dr. George J. Mead, Chairman.  
 Dr. George W. Lewis, National Advisory Committee for Aeronautics, Vice Chairman.  
 Comdr. Rico Botta, United States Navy.  
 Dr. H. O. Dickinson, National Bureau of Standards.  
 John H. Geisse, Civil Aeronautics Authority.  
 Carlton Kemper, National Advisory Committee for Aeronautics.  
 Gaylord W. Newton, Civil Aeronautics Authority.  
 Maj. E. R. Page, Air Corps, United States Army, Matériel Division, Wright Field.

## SUBCOMMITTEE ON AIRCRAFT FUELS AND LUBRICANTS

Dr. George W. Lewis, National Advisory Committee for Aeronautics, Chairman.  
 Commander Rico Botta, United States Navy.  
 Dr. O. C. Bridgeman, National Bureau of Standards.  
 H. K. Cummings, National Bureau of Standards.  
 Dr. H. C. Dickinson, National Bureau of Standards.  
 Lt. Henry R. Dozier, United States Navy.  
 L. S. Hobbs, The Pratt and Whitney Aircraft Company.  
 Robert V. Kerley, Matériel Division, Army Air Corps, Wright Field.  
 Gaylord W. Newton, Civil Aeronautics Authority.  
 Arthur Nutt, Wright Aeronautical Corporation.  
 Maj. E. R. Page, Air Corps, United States Army, Matériel Division, Wright Field.  
 Addison M. Rothrock, National Advisory Committee for Aeronautics.

## COMMITTEE ON AIRCRAFT MATERIALS

Dr. L. J. Briggs, National Bureau of Standards, Chairman.  
 Prof. H. L. Whittemore, National Bureau of Standards, Vice Chairman.  
 S. K. Colby, Aluminum Co. of America.  
 Lt. Comdr. C. F. Cotton, United States Navy.  
 Edgar H. Dix, Jr., American Magnesium Corporation.  
 John Easton, Civil Aeronautics Authority.  
 Warren E. Emley, National Bureau of Standards.  
 Capt. Garland Fulton, United States Navy.  
 J. T. Gray, Civil Aeronautics Authority.  
 C. H. Helms, National Advisory Committee for Aeronautics.  
 J. B. Johnson, Matériel Division, Army Air Corps, Wright Field.  
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Dr. George J. Mead.

John F. Victory, Secretary.

During the past year the Committee has organized the following special committees for the study of particular problems:

#### SPECIAL SURVEY COMMITTEE ON AERONAUTICAL RESEARCH FACILITIES

Col. Charles A. Lindbergh, Chairman.

Maj. Gen. Henry H. Arnold, Chief of the Air Corps, United States Army, War Department.

Rear Admiral J. H. Towers, Chief, Bureau of Aeronautics, United States Navy, Navy Department.

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Dr. George W. Lewis, Director of Aeronautical Research, National Advisory Committee for Aeronautics.

Dr. Edward Warner, Civil Aeronautics Authority.

#### SPECIAL COMMITTEE ON NEW ENGINE RESEARCH FACILITIES

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R. M. Hazen, Allison Engineering Division, General Motors Corporation.

S. D. Heron, Ethyl Gasoline Corporation.

L. S. Hobbs, Pratt and Whitney Aircraft Company.

Carlton Kemper, National Advisory Committee for Aeronautics.

Gaylord W. Newton, Civil Aeronautics Authority.

Arthur Nutt, Wright Aeronautical Corporation.

Maj. E. R. Page, Air Corps, United States Army, Matériel Division, Wright Field.

#### TECHNICAL PUBLICATIONS OF THE COMMITTEE

The Committee has four series of publications, namely, technical reports, technical notes, technical memorandums, and aircraft circulars.

The technical reports present the results of fundamental research in aeronautics. The technical notes are mimeographed and present the results of short research investigations and the results of studies of specific detailed problems which form parts of long investigations. The technical memorandums are mimeographed and contain translations and reproductions of important foreign aeronautical articles. The aircraft circulars are mimeographed and contain descriptions of new types of foreign aircraft. No aircraft circulars were issued during the past year.

The following are lists of the publications issued:

#### LIST OF TECHNICAL REPORTS ISSUED DURING THE PAST YEAR

645. Correction of Temperatures of Air-Cooled Engine Cylinders for Variation in Engine and Cooling Conditions. By Oscar W. Schey, Benjamin Pinkel, and Herman H. Ellerbrock, Jr., N. A. C. A.
646. The Compressibility Bubble and the Effect of Compressibility on Pressures and Forces Acting on an Airfoil. By John Stack, W. F. Lindsey, and Robert E. Littell, N. A. C. A.
647. Tests of N. A. C. A. 0009, 0012, and 0018 Airfoils in the Full-Scale Tunnel. By Harry J. Goett and W. Kenneth Bullivant, N. A. C. A.
648. Design Charts for Predicting Downwash Angles and Wake Characteristics behind Plain and Flapped Wings. By Abe Silverstein and S. Katzoff, N. A. C. A.
649. The "Pack" Method for Compressive Tests of Thin Specimens of Materials Used in Thin-Wall Structures. By C. S. Aitchison and L. B. Tuckerman, National Bureau of Standards.
650. The Aerodynamic Characteristics of Six Full-Scale Propellers Having Different Airfoil Sections. By David Biermann and Edwin P. Hartman, N. A. C. A.
651. Downwash and Wake behind Plain and Flapped Airfoils. By Abe Silverstein, S. Katzoff, and W. Kenneth Bullivant, N. A. C. A.
652. Air Flow in the Boundary Layer of an Elliptic Cylinder. By G. B. Schubauer, National Bureau of Standards.
653. A Study of Air Flow in an Engine Cylinder. By Dana W. Lee, N. A. C. A.
654. General Airplane Performance. By W. C. Rockefeller, California Institute of Technology.
655. The Knocking Characteristics of Fuels in Relation to Maximum Permissible Performance of Aircraft Engines. By A. M. Rothrock and Arnold E. Biermann, N. A. C. A.
656. The Column Strength of Two Extruded Aluminum-Alloy H-Sections. By William R. Osgood and Marshall Holt, National Bureau of Standards and Aluminum Company of America.
657. The Influence of Directed Air Flow on Combustion in a Spark-Ignition Engine. By A. M. Rothrock and R. C. Spencer, N. A. C. A.
658. Tests of Two Full-Scale Propellers with Different Pitch Distributions, at Blade Angles up to 60°. By David Biermann and Edwin P. Hartman, N. A. C. A.
659. Effect of Service Stresses on Impact Resistance, X-ray Diffraction Patterns, and Microstructure of 25S Aluminum Alloy. By J. A. Kies and G. W. Quick, National Bureau of Standards.
660. Experimental Investigation of the Momentum Method for Determining Profile Drag. By Harry J. Goett, N. A. C. A.
661. Tests in the Variable-Density Wind Tunnel of the N. A. C. A. 23012 Airfoil with Plain and Split Flaps. By Ira H. Abbott and Harry Greenberg, N. A. C. A.
662. Design of N. A. C. A. Cowlings for Radial Air-Cooled Engines. By George W. Stickle, N. A. C. A.
663. The Effect of Continuous Weathering on Light Metal Alloys Used in Aircraft. By Willard Mutchler, National Bureau of Standards.
664. Wind-Tunnel Investigation of an N. A. C. A. 23012 Airfoil with Various Arrangements of Slotted Flaps. By Carl J. Wenzinger and Thomas A. Harris, N. A. C. A.
665. Calculation of the Aerodynamic Characteristics of Tapered Wings with Partial-Span Flaps. By Henry A. Pearson and Raymond F. Anderson, N. A. C. A.
666. Aircraft Rate-of-Climb Indicators. By Daniel P. Johnson, National Bureau of Standards.
667. Determination of the Profile Drag of an Airplane Wing in Flight at High Reynolds Numbers. By Joseph Bicknell, N. A. C. A.
668. Wind-Tunnel Investigation of N. A. C. A. 23012, 23021, and 23030 Airfoils with Various Sizes of Split Flap. By Carl J. Wenzinger and Thomas A. Harris, N. A. C. A.
669. Airfoil Section Data Obtained in the N. A. C. A. Variable-Density Tunnel as Affected by Support Interference and Other Corrections. By Eastman N. Jacobs and Ira H. Abbott, N. A. C. A.
670. Tensile Elastic Properties of 18:8 Chromium-Nickel Steel as Affected by Plastic Deformation. By D. J. McAdam, Jr., and R. W. Mebs, National Bureau of Standards.
671. A Theoretical Study of the Moment on a Body in a Compressible Fluid. By Carl Kaplan, N. A. C. A.
672. Free-Spinning Wind-Tunnel Tests of a Low-Wing Monoplane with Systematic Changes in Wings and Tails. IV. Effect of Center-of-Gravity Location. By Oscar Seidman and A. I. Nelhouse, N. A. C. A.
673. Experimental Verification of the Theory of Oscillating Airfoils. By Abe Silverstein and Upshur T. Joyner, N. A. C. A.
674. Cooling on the Front of an Air-Cooled Engine Cylinder in a Conventional Engine Cowling. By M. J. Brevoort and U. T. Joyner, N. A. C. A.
675. Effects of Elevator Nose Shape, Gap, Balance and Tabs on the Aerodynamic Characteristics of a Horizontal Tail Surface. By Harry J. Goett and J. P. Reeder, N. A. C. A.
676. Surface Heat-Transfer Coefficients of Finned Cylinders. By Herman H. Ellerbrock, Jr., and Arnold Biermann, N. A. C. A.



677. Wind-Tunnel Investigation of an N. A. C. A. 23021 Airfoil with Various Arrangements of Slotted Flaps. By Carl J. Wenzinger and Thomas A. Harris, N. A. C. A.
678. Interference of Tail Surfaces and Wing and Fuselage from Tests of 17 Combinations in the N. A. C. A. Variable-Density Tunnel. By Albert Sherman, N. A. C. A.
679. Wind-Tunnel Investigation of an N. A. C. A. 23012 Airfoil with a Slotted Flap and Three Types of Auxiliary Flap. By Carl J. Wenzinger and William E. Gauvain, N. A. C. A.
680. The Effect of Nacelle-Propeller Diameter Ratio on Body Interference and on Propeller and Cooling Characteristics. By James G. McHugh and Eldridge H. Derring, N. A. C. A.

#### LIST OF TECHNICAL NOTES ISSUED DURING THE PAST YEAR

- No.
667. Operational Treatment of the Nonuniform-Lift Theory in Airplane Dynamics. By Robert T. Jones, N. A. C. A.
668. Hydrodynamic and Aerodynamic Tests of Models of Flying-Boat Hulls Designed for Low Aerodynamic Drag—N. A. C. A. Models 74, 74-A, and 75. By Starr Truscott, J. B. Parkinson, John W. Ebert, Jr., and E. Floyd Valentine, N. A. C. A.
669. The Drag of Inflatable Rubber De-icers. By Russell G. Robinson, N. A. C. A.
670. N. A. C. A. Stall-Warning Indicator. By F. L. Thompson, N. A. C. A.
671. A Method of Rapidly Estimating the Position of the Laminar Separation Point. By Albert E. von Doenhoff, N. A. C. A.
672. Flow Observations with Tufts and Lampblack of the Stalling of Four Typical Airfoil Sections in the N. A. C. A. Variable-Density Tunnel. By Ira H. Abbott and Albert Sherman, N. A. C. A.
673. The Pressure Available for Ground Cooling in Front of the Cowling of Air-Cooled Airplane Engines. By George W. Stickle and Upshur T. Joyner, N. A. C. A.
674. Scavenging a Piston-Ported Two-Stroke Cylinder. By A. R. Rogowski and C. L. Bouchard, Massachusetts Institute of Technology.
675. The Charging Process in a High-Speed, Single-Cylinder, Four-Stroke Engine. By Blake Reynolds, Harry Shecter, and E. S. Taylor, Massachusetts Institute of Technology.
676. Discharge Characteristics of a Simulated Unit Injection System. By Edred T. Marsh, N. A. C. A.
677. Tests of a Contra-Propeller for Aircraft. By William M. Benson, Daniel Guggenheim Aeronautical Laboratory, Stanford University.
678. Hydrodynamic and Aerodynamic Tests of Four Models of Outboard Floats (N. A. C. A. Models 51-A, 51-B, 51-C, 51-D). By John R. Dawson and Edwin P. Hartman, N. A. C. A.
679. Noise from Propellers with Symmetrical Sections at Zero Blade Angle, II. By A. F. Deming, N. A. C. A.
680. The Aerodynamic Drag of Five Models of Side Floats, N. A. C. A. Models 51-E, 51-F, 51-G, 51-H, and 51-J. By R. O. House, N. A. C. A.
681. A General Tank Test of a Model of the Hull of the P3M-1 Flying Boat Including a Special Working Chart for the Determination of Hull Performance. By John R. Dawson, N. A. C. A.
682. The Unsteady Lift of a Finite Wing. By Robert T. Jones, N. A. C. A.
683. Pressure-Distribution Measurements on a Tapered Wing with a Full-Span Split Flap in Curved Flight. By Th. Troller and F. Rokus, Daniel Guggenheim Airship Institute, Akron, Ohio.
684. Experimental Study of Deformation and of Effective Width in Axially Loaded Sheet-Stringer Panels. By Walter Ramberg, Albert E. McPherson, and Sam Levy, National Bureau of Standards.
685. Circulation Measurements about the Tip of an Airfoil During Flight through a Gust. By Arnold M. Kuethe, Daniel Guggenheim Airship Institute, Akron, Ohio.
686. Local Instability of Symmetrical Rectangular Tubes Under Axial Compression. By Eugene E. Lundquist, N. A. C. A.
687. Loads Imposed on Intermediate Frames of Stiffened Shells. By Paul Kuhn, N. A. C. A.
688. Comparative Performance of Engines Using a Carburetor, Manifold Injection, and Cylinder Injection. By Oscar W. Schey and J. Denny Clark, N. A. C. A.
689. Tandem Air Propellers. By E. P. Lesley, Daniel Guggenheim Aeronautical Laboratory, Stanford University.
690. Résumé of Air-Load Data on Slats and Flaps. By Carl J. Wenzinger and Francis M. Rogallo, N. A. C. A.
691. Some Elementary Principles of Shell Stress Analysis with Notes on the Use of the Shear Center. By Paul Kuhn, N. A. C. A.
692. Some Fundamental Considerations in Regard to the Use of Power in Landing an Airplane. By Walter S. Diehl, Bureau of Aeronautics, Navy Department.
693. Comparison of Profile-Drag and Boundary-Layer Measurements Obtained in Flight and in the Full-Scale Wind Tunnel. By Harry J. Goett and Joseph Bicknell, N. A. C. A.
694. Physical Properties of Synthetic Resin Materials. By Meyer Fishbein, N. A. C. A.
695. The Effects of Some Common Surface Irregularities on Wing Drag. By Manley J. Hood, N. A. C. A.
696. Torsional Stability of Aluminum Alloy Seamless Tubing. By R. L. Moore and D. A. Paul, Aluminum Research Laboratories, Aluminum Company of America.
697. The Frequency of Torsional Vibration of a Tapered Beam. By Robert P. Coleman, N. A. C. A.
698. Propeller Tests to Determine the Effect of Number of Blades at Two Typical Solidities. By E. P. Lesley, Daniel Guggenheim Aeronautical Laboratory, Stanford University.
699. Tests of an N. A. C. A. 23012 Airfoil with a Slotted Deflector Flap. By R. O. House, N. A. C. A.
700. Theory of Automatic Control of Airplanes. By Herbert K. Weiss, Massachusetts Institute of Technology.
701. Intermittent-Flow Coefficients of a Poppet Valve. By C. D. Waldron, N. A. C. A.
702. Wind-Tunnel Tests of Several Forms of Fixed Wing Slot in Combination with a Slotted Flap on an N. A. C. A. 23012 Airfoil. By M. J. Bamber, N. A. C. A.
703. Wind-Tunnel Investigation of Effect of Yaw on Lateral-Stability Characteristics. I—Four N. A. C. A. 23012 Wings of Various Plan Forms with and without Dihedral. By M. J. Bamber and R. O. House, N. A. C. A.
704. Some Notes on the Numerical Solution of Shear-Lag and Mathematically Related Problems. By Paul Kuhn, N. A. C. A.
705. Wind-Tunnel Investigation of Ground Effect on Wings with Flaps. By Isidore G. Recant.



706. An Experimental Investigation of the Normal Acceleration of an Airplane Model in a Gust. By Philip Donely, N. A. C. A.
707. Compression-Ignition Engine Performance with Undoped and Doped Fuel Oils and Alcohol Mixtures. By Charles S. Moore and Hampton H. Foster, N. A. C. A.
708. A Simplified Method for the Calculation of Airfoil Pressure Distribution. By H. Julien Allen, N. A. C. A.
709. A Semigraphical Method for Analyzing Strains Measured on Three or Four Gage Lines Intersecting at 45°. By H. N. Hill, Aluminum Research Laboratories, Aluminum Company of America.
710. A Comparison of Ignition Characteristics of Diesel Fuels as Determined in Engines and in a Constant-Volume Bomb. By Robert F. Selden, N. A. C. A.
711. An Approximate Spin Design Criterion for Monoplanes. By Oscar Seidman and Charles J. Donlan, N. A. C. A.
712. A Preliminary Study of the Prevention of Ice on Aircraft by the Use of Engine-Exhaust Heat. By Lewis A. Rodert, N. A. C. A.
713. A Comparison of Several Tapered Wings Designed to Avoid Tip Stalling. By Raymond F. Anderson, N. A. C. A.
714. Flight Tests of Retractable Ailerons on a Highly Tapered Wing. By J. W. Wetmore, N. A. C. A.
715. Wind-Tunnel Investigation of an N. A. C. A. 23012 Airfoil with Two Arrangements of a Wide-Chord Slotted Flap. By Thomas A. Harris, N. A. C. A.
716. Hydrodynamic and Aerodynamic Tests of a Family of Models of Seaplane Floats with Varying Angles of Dead Rise N. A. C. A. Models 57-A, 57-B, and 57-C. By John B. Parkinson, Roland E. Olson, and Rufus O. House, N. A. C. A.
717. A Method of Estimating the Critical Buckling Load for Structural Members. By Eugene E. Lundquist, N. A. C. A.
718. Resistance of Transparent Plastics to Impact. By Benjamin M. Axilrod and Gordon M. Kline, National Bureau of Standards.
719. The Effects of Partial-Span Slotted Flaps on the Aerodynamic Characteristics of a Rectangular and a Tapered N. A. C. A. 23012 Wing. By Rufus O. House, N. A. C. A.
720. Flight Tests of N. A. C. A. Nose-Slot Cowlings on the BFC-1 Airplane. By George W. Stickle, N. A. C. A.
721. Compressive Tests of a Monocoque Box. By Walter Ramberg, Albert E. McPherson, and Sam Levy, National Bureau of Standards.
722. Local Instability of Centrally Loaded Columns of Channel Section and Z-Section. By Eugene E. Lundquist, N. A. C. A.
723. Adhesion of Ice in Its Relation to the De-Icing of Airplanes. By A. M. Rothrock and R. F. Selden, N. A. C. A.
724. The Effects of Surface Waviness and of Rib Stitching on Wing Drag. By Manley J. Hood, N. A. C. A.
725. Tank Tests to Determine the Effects of the Chine Flare of a Flying-Boat Hull N. A. C. A. Model Series 62 and 69. By Joe W. Bell and Roland E. Olson, N. A. C. A.
726. Combined Beam-Column Stresses of Aluminum-Alloy Channel Sections. By R. Gottlieb, T. M. Thompson, and E. C. Witt, University of Maryland.
727. A Flight Investigation of the Distribution of Ice-Inhibiting Fluids on a Propeller Blade. By Lewis A. Rodert, N. A. C. A.
728. Wind-Tunnel Investigation of an N. A. C. A. 23021 Airfoil with Two Arrangements of a 40-Percent-Chord Slotted Flap. By Frank Duschik, N. A. C. A.

729. An Instrument for Estimating Tautness of Doped Fabrics on Aircraft. By Gordon M. Kline and Herbert F. Schiefer, National Bureau of Standards.

730. Wind-Tunnel Investigation of Effect of Yaw on Lateral-Stability Characteristics. II—Rectangular N. A. C. A. 23012 Wing with a Circular Fuselage and a Fin. By M. J. Bamber and R. O. House, N. A. C. A.

#### LIST OF TECHNICAL MEMORANDUMS ISSUED DURING THE PAST YEAR

878. The Twisting of Thin-Walled Stiffened Circular Cylinders. By E. Schapitz. From Lillenthal-Gesellschaft für Luftfahrtforschung Jahrbuch, 1938.
879. Static Longitudinal Stability and Longitudinal Control of Autogiro Rotors. By M. Schrenk. From Luftfahrtforschung, June 6, 1938.
880. The Effective Width of Curved Sheet after Buckling. By W. A. Wenzek. From Luftfahrtforschung, July 6, 1938.
881. Application and Testing of Transparent Plastics Used in Airplane Construction. By K. Riechers and J. Olms. From Luftwissen, June 1938.
882. Modern Manufacturing Equipment of the Ernst Heinkel Airplane Works. By A. Thormann and H. Jockisch. From Luftfahrtforschung, January 20, 1938.
883. Distribution of Temperatures over an Airplane Wing with Reference to the Phenomena of Ice Formation. By Edmond Brun. From Publications Scientifiques et Techniques du Ministère de l'Air, No. 119, 1938.
884. Calculation of the Induced Efficiency of Heavily Loaded Propellers Having Infinite Number of Blades. By F. Lösch.  
The Induced Efficiency of Optimum Propellers Having a Finite Number of Blades. By K. N. Kramer.  
Prospects of Propeller Drive for High Flying Speeds. By G. Bock and R. Nikodemus.  
From Luftfahrtforschung, July 6, 1938.
885. Meteorological-Physical Limitations of Icing in the Atmosphere. By W. Findelsen. From Hauptversammlung der Lillenthal-Gesellschaft für Luftfahrtforschung, Berlin, October 12-15, 1938.
886. Theory of Two-Dimensional Potential Flow about Arbitrary Wing Sections. By H. Gebelein. From Ingenieur-Archiv, June 1938.
887. Comparison of Theory with Experiment in the Phenomenon of Wing Flutter. By P. Cicala. From L'Aerotecnica, April 1938.
888. Ice Formation on Wings. By L. Ritz. From Hauptversammlung der Lillenthal-Gesellschaft für Luftfahrtforschung, Berlin, October 12-15, 1938.
889. Investigation of the Lift Distribution Over the Separate Wings of a Biplane. By D. Küchemann. From Luftfahrtforschung, October 10, 1938.
890. Experiments on a Slotted Wing. By P. Ruden. From Deutsche Luftfahrtforschung Jahrbuch, 1937.
891. Theoretical and Experimental Study of Ignition Lag and Engine Knock. By Fritz A. F. Schmidt. From VDI-Forschungsheft 892—Supplement to Forschung auf dem Gebiete des Ingenieurwesens, September-October, 1938.
892. Investigations and Tests in the Towing Basin at Guidonia. By C. Cremona. From Hauptversammlung der Lillenthal-Gesellschaft für Luftfahrtforschung, Berlin, October 12-15, 1938.

893. Contribution to the Theory of the Heated Duct Radiator. By H. Winter. From *Luftfahrtforschung*, October 10, 1938.
894. The Way to Increased Airplane Engine Power. By Eugen Vohrer. From *Luftwissen*, October 1938.
895. The Power of Aircraft Engines at Altitude. By Paolo Ragazzi. From *Hauptversammlung der Lilienthal-Gesellschaft für Luftfahrtforschung*, Berlin, October 12-15, 1938.
896. The Drag of Airplane Radiators with Special Reference to Air Heating (Comparison of Theory and Experiment). By B. Göthert. From *Luftfahrtforschung*, September 10, 1938.
897. Airfoil Theory at Supersonic Speed. By H. Schlichting. From *Deutsche Luftfahrtforschung Jahrbuch*, 1937.
898. The Limit of Stability of a Curved Plate Strip Under Shear and Axial Stresses. By A. Kromm. From *Luftfahrtforschung*, October 10, 1938.
899. The Hydrodynamic Theory of Detonation. By Heinz Langweiler. From *Zeitschrift für Technische Physik*, Vol. 19, No. 9, 1938.
900. The Effect of the Masses of the Controls on the Longitudinal Stability with Free Elevator. By Rudolf Schmidt. Part I. From *Luftfahrtforschung*, January 10, 1939.
901. Investigations and Experiments in the Guidonia Supersonic Wind Tunnel. By Antonio Ferri. From *Hauptversammlung der Lilienthal-Gesellschaft für Luftfahrtforschung*, Berlin, October 12-15, 1938.
902. Design of Centrifugal Impeller Blades. By A. Betz and I. Flüge-Lotz. From *Ingenieur-Archiv*, December 1938.
903. Effect of Transition in Cross-Sectional Shape on the Development of the Velocity and Pressure Distribution of Turbulent Flow in Pipes. By Erwin Mayer. From *VDI-Forschungsheft 389—Supplement to Forschung auf dem Gebiete des Ingenieurwesens*, March/April 1938.
904. Stability of Rectangular Plates with Longitudinal or Transverse Stiffeners Under Uniform Compression. By R. Barbre. From *Ingenieur-Archiv*, Vol. VIII, No. 2, 1937.
905. Temperature-Indicating Paints. By F. Penzig. From *Zeitschrift des Vereines deutscher Ingenieure*, January 21, 1939.
906. Forces and Moments on a Yawed Airfoil. By Sigward Hoerner. From *Luftfahrtforschung*, April 20, 1939.
907. Dynamic Stability of a Helicopter with Hinged Rotor Blades. By K. Hohenemser. From *Ingenieur-Archiv*, December 1938.
908. Two-Stroke-Cycle Engines with Unsymmetrical Control Diagram (Supercharged Engines). By J. Zeman. From *Automobiltechnische Zeitschrift*, August 25, 1938.
909. The Theory of Contra-Vanes Applied to the Propeller. By Albert Betz. From *Ingenieur-Archiv*, December 1938.
910. Measurements on a Low-Wing Model in the Rotating Jet and Comparison with Flight Measurements. By W. Bader. From *Luftfahrtforschung*, February 20, 1939.
911. Knocking in the Otto-Cycle Engine. By H. Weinhart. From *Luftfahrtforschung*, February 20, 1939.

#### FINANCIAL REPORT

**Appropriations and expenditures, 1939.**—The general appropriation for the National Advisory Committee for Aeronautics for the fiscal year 1939, as contained in the Independent Offices Appropriation Act approved May 23, 1938, was \$1,679,000. A supplemental appropria-

tion of \$223,980 was made available in the Second Deficiency Appropriation Act, fiscal year 1939, approved May 2, 1939, for the same purposes specified in the Committee's regular appropriation act for 1939, to continue available until June 30, 1940. The total amount available for general purposes during the fiscal year 1939, therefore, was \$1,902,980. The amount expended and obligated under the regular appropriation was \$1,678,996 and under the supplemental appropriation \$29,434, making a total of \$1,708,430, itemized as follows:

Personal services	\$1,005,812
Supplies and materials	85,146
Communication service	8,722
Travel expenses	15,185
Transportation of things	2,479
Furnishing of electricity	43,518
Repairs and alterations	5,820
Special and miscellaneous investigations	69,384
Contracts for research	24,008
Equipment	192,446
Structures	200,000
Expended and obligated	1,708,430
Unexpended balance	4
Balance of supplemental appropriation, available for expenditure during fiscal year 1940	194,546
Total, general appropriation	1,902,980

The appropriation for printing and binding for 1939 was \$21,000, of which \$20,996 was expended.

The Second Deficiency Appropriation Act also provided \$2,140,000 for the construction and equipment of additional facilities at Langley Field, Va., including connections to public utilities, and rights-of-way for, and installation of power lines, this amount to remain available until expended. No obligations were placed under this fund during the fiscal year 1939.

The amount of \$6,500 was received during the fiscal year 1939 and credited to three special deposit accounts to cover the cost of scientific investigations for manufacturers. Also one remittance of \$1,130 was carried over on account of an uncompleted investigation started in 1938. These four investigations were completed during 1939, resulting in the deposit of \$6,345.52 to Miscellaneous Receipts in the Treasury, as proceeds, and the return of unexpended balances totaling \$1,284.48 to depositors.

An allotment of \$400 was received from the State Department for payments during the fiscal year 1939 to employees stationed abroad, on account of exchange losses due to appreciation of foreign currencies. Of this amount \$71 was paid during the fiscal year 1939 to employees of the Committee stationed in the Paris office, leaving a balance of \$329 which was turned back into the Treasury.

An allotment of \$1,000 was made to the Committee for preparation of models for exhibit at the Golden Gate International Exposition at San Francisco. The total amount was expended for that purpose.

**Appropriations for fiscal year 1940.**—The general appropriation for the fiscal year 1940, as contained in the Independent Offices Appropriation Act approved March 16, 1939, was \$1,717,000, and the amount provided for printing and binding was \$23,000. This act also provided \$340,000 for the completion of the two-dimensional wind tunnel for which the 1939 act had provided an initial amount of \$200,000, and \$100,000 which will be used for the modernization of the free spinning wind tunnel. The total amount provided under the Independent Offices Act for 1940, therefore was \$2,180,000.

The Second Deficiency Appropriation Act, fiscal year 1939, approved May 2, 1939, provided \$2,140,000 for the construction and equipment of additional facilities at Langley Field, Va., including connections to public utilities, and rights-of-way for, and installation of power lines, this amount to remain available until expended. Also provided under the Second Deficiency Act for general purposes for the fiscal years 1939 and 1940 was an additional sum of \$223,980, of which there was at the end of the fiscal year 1939 a balance of \$194,546 available for obligation in the fiscal year 1940, thus making the total amount available under this act for expenditure in 1940, \$2,334,546.

The Third Deficiency Appropriation Act, fiscal year 1939, approved August 9, 1939, provided \$1,890,980 for beginning construction of an additional research laboratory and authorized the Committee to enter into contracts for construction and equipment, including the purchase of land, not to exceed a total of \$10,000,000. Also included in this act was an item of \$109,020 for additional personnel, making the total amount of \$2,000,000 available under this act for expenditure during 1940.

The total amount available for expenditure during 1940 under the three acts mentioned is \$6,514,546.

**Estimates for fiscal year 1941.**—The Committee's estimates for the fiscal year 1941 include the amount of \$3,899,513 for general purposes and \$30,000 for printing and binding. The amount of \$1,177,475 is requested for additional facilities at Langley Field, and \$5,699,020 for construction of new facilities at Moffett Field. The total amount of the regular estimates for 1941 is \$10,806,008.

#### CONCLUSION

The Committee is grateful to the President and to the Congress for the liberal support of its work in the past and especially for the recent approval of a second major research station to be located at Moffett Field, Calif. It strongly urges approval of its recommendations for the construction of a special engine research laboratory and for the stimulation and support of research in scientific and educational institutions.

In the present disturbed condition of world affairs, the importance of accelerating aeronautical progress in the United States cannot be overemphasized. The Committee has been careful and practical in presenting its needs and urges that the appropriations recommended be approved. Nothing will have a more fundamental influence on the progress of American aeronautics than liberal support of a well-rounded and comprehensive program for scientific research. The Army, the Navy, and the Civil Aeronautics Authority depend upon the National Advisory Committee for Aeronautics to meet the research needs of aviation and to provide the constant stream of new knowledge necessary to keep the United States in the forefront of progressive nations in the development of aeronautics for both military and commercial purposes.

Respectfully submitted.

NATIONAL ADVISORY COMMITTEE  
FOR AERONAUTICS,  
VANNEVAR BUSH, *Chairman*.